METAL PROGRESS

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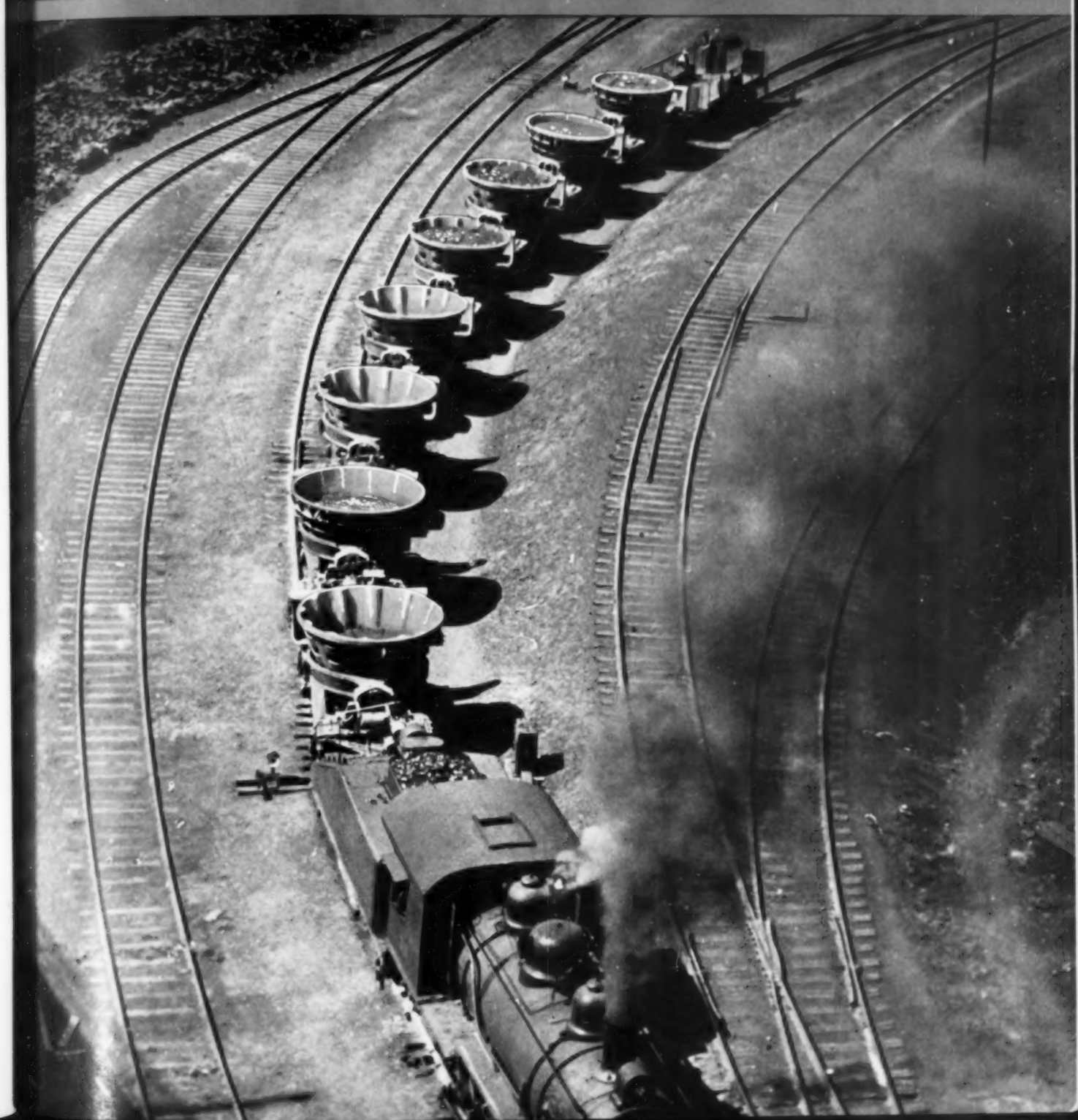

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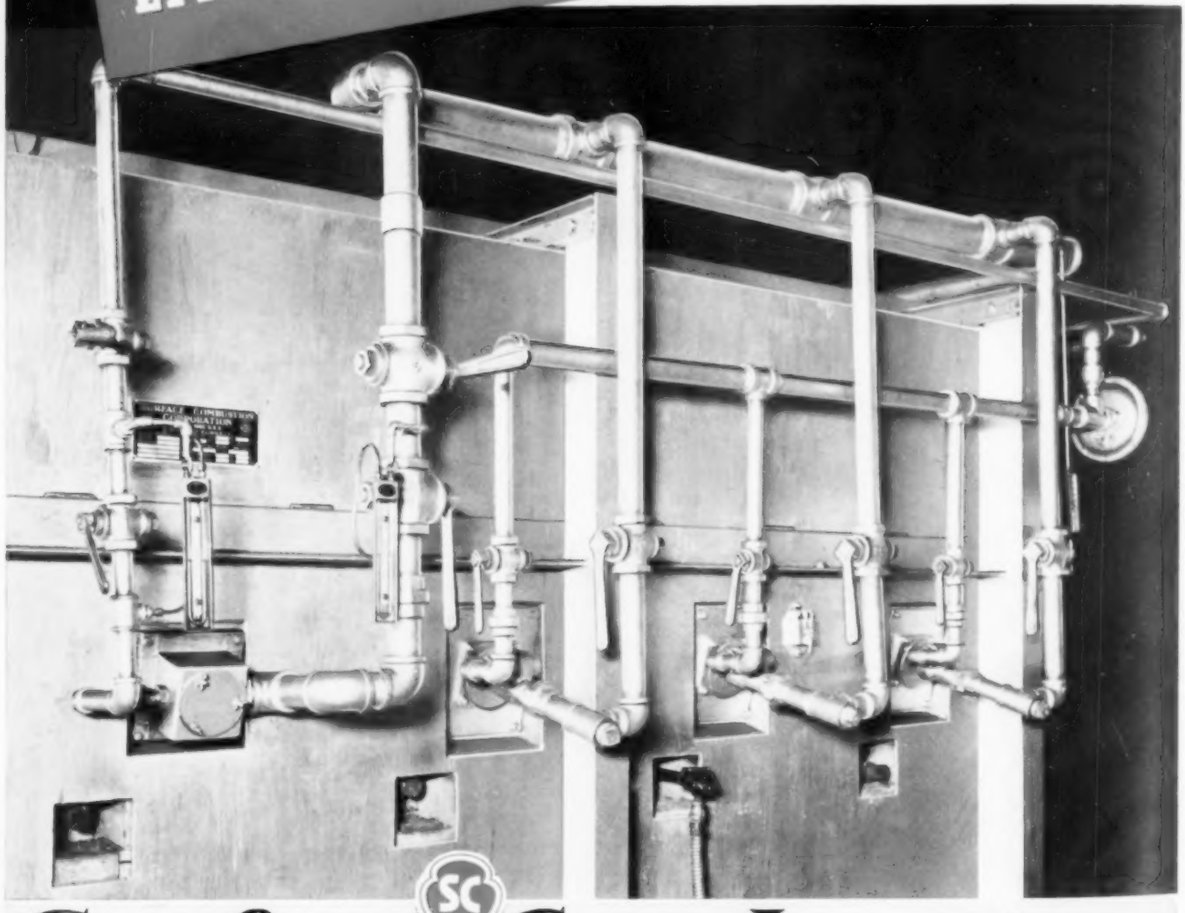

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Metal Progress

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The Light Metals

for trucks, trains, ships

While aluminum and magnesium have become paramount for aircraft construction, their greatest future in automotive applications is probably in trucks and busses where economical operation is imperative. Thirty-year-old ships and railroad equipment will be replaced with sleek new designs, using important amounts of these two light metals

APPLICATIONS OF ALUMINUM AND ITS STRONG ALLOYS in the transportation field have grown with extraordinary rapidity in the past five years. An outstanding example is aircraft: The types of planes in production in 1930 were analyzed by J. B. Johnson of the Air Corps, U. S. Army, and found to utilize one-third the weight of structure and accessories in aluminum. Each engine on the average took 220 lb. more of it. By 1935 these proportions had increased to over three-quarters of the structure and 900 lb. per engine.

Railroad passenger cars with considerable aluminum appeared in the 1920's, but prior to 1933 the applications were confined to roof, doors and trim. Recently greater use has been made of plates and rolled or extruded shapes of the duralumin-type alloys. These alloys are comparable with mild structural steel in strength, and permit the maximum weight reduction while the design retains a necessary reserve of strength. The same reasons have warranted similar construction for motor busses. To date about 5000 vehicles have consumed 21,000,000 lb. of aluminum as a major material of construction.

In the truck and trailer field the consumption of aluminum and magnesium alloys, begun in 1929, is rapidly growing. Light weight construction is warranted by one or a combination of the following factors: Pay load increased 20%; power requirements decreased; speed increased.

So much for the immediate past. What can be said of the place the light metals, aluminum and magnesium, will occupy in the transportation of the future?

Iron and steel will doubtless be the principal reliance of marine, railroad and automobile equipment for as long as most of us care much about. Similarly, the light metals will be paramount in airplanes and airships where weight *must* be saved regardless of cost. Intermediate between these extremes are many applications where operating economies are more closely figured and obviously the future decisions will depend on improvements in the competing metals and the price structure in the entire metal industry, ferrous and non-ferrous.

Trend toward light metal in truck bodies and tanks has not reached a peak. Extremely light or fairly heavy designs may at any time be dictated by new regulations promulgated by highway and bridge departments in this state or that. Purchasers of aircraft, busses and (to a smaller extent) trucks know the economics of their transportation services, and are willing to pay higher prices for the original equipment if these can be more than offset by lower operating costs.

John Citizen, on the other hand, knows little about the over-all cost of operating his automobile and seldom cares. Low first cost will always be an important factor in selling to him. There-

fore a finished part made of light metal must be cheaper than an identical part made from steel in order to get any preference. Good looks may help swing the decision one way or another on exposed parts.

With reference to the railroads, it is clear that the light weight passenger coaches have shown sufficient promise to whet the appetite of railroad excutives for more. Of the real light-weight units, three types are now on trial: One is the stainless steel unit made of thin sheet material; another is strong aluminum alloy sheet with the airship type of construction; the third is strong aluminum alloy made along the more conventional lines of steel construction. Railroad operators, not being metallurgists, are more or less indifferent to the competing claims of these types. They are most interested in reliable equipment which will attract customers and be cheap to operate. It will no doubt take considerable time to determine the true economics of the situation. Here again, the best answer for one region, road or division will probably be second best in another combination of circumstances.

If we consider the transportation industry as substantially stabilized, which of course it is not, we may obtain a general idea of the future demand for its construction materials. Aircraft equipment should perhaps not be used on the average for more than five years. The whole industry with this assumption would be rebuilt every five years. The average equipment would be about two and one-half years old, and there should not be extreme differences between the old and the new.

The average automobile is about four years old. New cars therefore reflect an eight-year improvement over the oldest 10% in service. By contrast, ships, locomotives and rail cars must be called upon to last about 25 years, and the new units are far in advance of the oldest 10%. Compare the Normandie or the Europa with a 30-year old passenger ship, or one of the new stream-lined trains with a 30-year old train, and the contrast is striking.

Our transportation equipment must therefore be substantially replaced in from 5 to 25 years, depending on type and service. This rebuilding will be more on the order of the 1935 or 1940 than that of the older equipment; hence, more light, strong metal, ferrous and non-ferrous, will be utilized than obtains in the current structures.

It even seems likely that the 1936 model motor cars, trucks, trains and ships will be regarded some years hence as having too little light metal for economic operation. This forecast seems probable because the consumption curve of light metal in the transportation field has risen more steeply than in other fields during the last ten years, and this equipment has been purchased by those having the best knowledge of the true cost of transportation services.

Modern Metallic Arc Welding

A MOST INGENIOUS SERIES OF EXPERIMENTS HAS been used to explore conditions existing in the welding arc at the research laboratory of A. O. Smith Corp. in Milwaukee and described recently by Louis J. Larson before a meeting of the American Welding Society. Shadowgraphs, slow motion pictures and oscillograph records have proven that when welding with bare wire, the end of the electrode melts and most of the metal is transferred in large drops — large enough to span the gap and cause a momentary short circuit. These observational methods do not show much about the modern method of welding with coated electrodes, and it is certain that the mechanism is then quite different, because short circuits are comparatively very rare.

The experiments to be described were made on a ¼-in. electrode, coated with a mixture of silicate and cellulose, the arc length being about $\frac{3}{16}$ in. to ¼ in., using direct current and electrode connected to negative pole. By passing a thin ribbon of copper so quickly through such an arc that it does not melt, it will come out covered with a shower of tiny globules of metal. If it is coated with a transparent sticky paste, so none of the impinging globules can bounce off, the relative number of certain sizes can be found. For every one which is 0.010 in. diameter there are about six of 0.005 in., and over 100 of 0.001 in., to say nothing of a multitude of even finer particles.

Next, by passing the ribbon through broadside, a good idea can be had of the number of these globules in unit volume.

Speed of motion was determined very cleverly: Two horizontal ribbons, one exactly above the other, and spaced a known distance apart (a "biplane") were passed through the arc at known speed. The distance a given particle landed from the leading edge of the lower ribbon was then a measure of its *slowest* velocity. Slowest speeds observed were on the order of 9 ft. per sec.; slow though this is, it is greatly in excess of the speed of free fall for so short a distance as 0.010 in.

The *maximum* speed was measured by pass-

ing the arc, held as in overhead welding, back and forth underneath a narrow slot in an iron plate, and photographing the trajectory of sparks shot up through the opening. The camera's shutter was closed momentarily at 0.05-sec. intervals, so each spark-track was a dot and dash from which its speed could be calculated at any place. From the height to which the particles fly, from the decelleration by gravity (the principal stopping force on particles say 0.010 in. diameter), and from the decelleration by air resistance (the principal stopping force on particles say 0.001 in. diameter), the size of the particles could be computed as well as the original velocity with which they were shot away from the hot electrode. A velocity distribution was thus secured for each size-group; maximum speeds were on the order of 125 ft. per sec.

Data as to size, number and speed of the various classifications were then available, and a picture of the metallic conditions in the arc can be drawn. It is mostly open space — that is to say, the particles are separated by distances many times their diameter. Knowing also the amount of metal lost by the electrode in a given time, it was calculated that about 90% of it passed across to the joint in globules 0.001 in. diameter and larger. Finer particles are present in infinite number, yet the amount of true metallic vapor in the arc is probably a small proportion of this remaining 10%.

At any rate, these fine particles of superheated metal must be protected from oxidation en route to the joint, and this is effectively done by the gases and slags arising from the electrode coating. When the same type of arc welding was done in a small closed chamber and the gases collected and analyzed they were found to be hydrogen and carbon monoxide in approximately equal volumes and a little carbon dioxide — an ideal combination.

Mr. Larson would venture no opinion as to why the metal passed from electrode to joint and not the other way, irrespective of polarity and even when alternating current is used. From other sources it was suggested that the heat is so highly concentrated at the end of the coated electrode that the iron is above 2450° C., its boiling point, whereas conduction and radiation keep the crater on the joint much cooler. On this assumption the temperature at the electrode must be so high that violent boiling throws off a spray of liquid globules. Perhaps some physico-metallurgic-mathematical expert can find some data about surface tensions and compute the temperature necessary to throw off particles of the size and speed actually found by Mr. Larson. If this supposition checks mathematically, someone else can tell us (eventually if not now) how to speed up welding by alloying the electrode with a substance innocuous to the welded joint yet which will materially reduce the surface tension and boiling point of iron, or will itself boil out vigorously at a lower temperature, thus blasting the molten metal away in larger particles.

A Mouse Squeaks

ARE ENGINEERS MICE OR ARE THEY MEN? I DON'T mean the renovating engineers, the human engineers, the traffic engineers and the other near-artisans and near-professionals who are anxious to appropriate the honorable title. I mean the engineers who don't care whether they have a title or not, and belong to the national societies and are wont to sit long hours in hot smoke-filled rooms, listening to erudite expositions of earth resistivity, cosmic rays, allotropic transformations, or seismic disturbances. Are they mice or are they men?

If they were worthy of the title engineer and the word man, would they endure a meeting room with ventilation zero, with temperature gradually mounting past 80, with humidity creeping up to 100%, with carbon dioxide reaching the lethal point, fitfully dozing on racks of torture misnamed chairs? Assuming that the engineers have heard of air conditioning and anti-fatigue devices, would they hire halls so inadequately equipped for creature comforts — let alone for intense intellectual concentration?

Extenuating circumstances may at times warrant such self immolation. It may, for instance, be thought necessary to hold a meeting in some backward American city, possessing only the pre-War conveniences, in order to stiffen the backbone of the local membership. Even granting that this is necessary and will be effective, why, even there, cannot these ingenious citizens devise some reliable means of communication between the lecturer and the magic lantern operator? With all that is known about telegraphy, telephony, radio, television, and even aids to the hard of hearing — why, oh why is it necessary to rely upon the ante-diluvian buzzer with a sticky button, a run-down battery, or a defective wire?

Are we mice or are we men? I'll say *men* when a lantern slide flashes on the screen, when, as and if wanted, right side up and reading from left to right. Until then, *mice*.

What Steel Is Best

for this or that part?

Steels used in automotive power and transmission units and reasons for their selection was the topic of one of the most interesting discussions ever held by the Detroit Chapter. Data were collected from six principal makers and reasons for the differences pointed out, such as design of part and fittings, fabricating routine and equipment available, accounting methods, nature of stresses, first cost, and experience with the steel

SINCE THE QUESTION "WHY DO AUTOMOBILE COMpanies use such different steels for almost identical parts?" has been asked so many times it seems quite appropriate to list the materials used for some of the important parts of passenger cars and to give one person's idea of the reasons for their selection.

The choice of steel for an automobile is always considered from three viewpoints, namely:

1. How does it function in service?

2. Can it be processed and if so, how economically?

3. How much does it cost?

There are so many factors influencing these viewpoints that one person cannot attempt to tell *why* some other company chooses a certain material — the materials may be taken at face value; the reasons given here represent only the author's opinion.

A cursory view clearly indicates a vast difference in the types of steels selected for the various parts and a still greater difference would be noticed if small differences in carbon content were considered. Small differences in carbon content are nearly always the result of difference in size of section or quenching medium, and because of this, no attempt will be made to classify the steels other than by S.A.E. numbers, which are all on a 10-point carbon range. It is rarely that an automobile company buys steel on a 10-point carbon range, so in using the data small differences must be passed over but not without realizing their importance.

By William H. Graves
Chief Metallurgist
Packard Motor Car Co.
Detroit, Mich.

Steels for Connecting Rods

Car 1	1040;	Brinell 196
Car 2	1045;	Brinell 217
Car 3	X-1335;	Brinell 207
Car 4	T-1335;	Brinell 248
Car 5	1045;	Brinell 196
Car 6	1040;	Brinell 302

While only three types are represented (straight carbon, high manganese, and high manganese and sulphur) carbon in one 1040 may be 0.35 to 0.40%, and in another 0.40 to 0.45% or perhaps 0.38 to 0.43%. Carbon actually specified in T-1335 is 0.33 to 0.38%, but in another forging nominally of T-1335 a different range may be acceptable to the purchaser.

Some of the rods are quenched and drawn to give higher physical properties. There can be only one reason for this operation, namely, the design calls for a stronger rod than can be obtained with simple normalizing. For instance, some rods have integral bolts which must be quenched and drawn for sufficient strength in the bolt.

Normalized rods of T-1335 are probably chosen for fast machining and less tool trouble, which offsets the increased cost of this steel, which is about 10¢ per car (eight-cylinder engine). Of course machining and tool costs vary considerably, plant to plant, not only because of different equipment but different accounting methods, so that two companies making identical parts may arrive at two different conclusions as to the most economical material.

Crankshaft (Cast Vs. Forged)

The crankshafts in five of the automobiles are made from a straight carbon S.A.E. 1045 forging, heat treated to Brinell 241 or 248. The sixth car uses an alloy casting.

The advantages of the cast shaft are: *(a)* Less finished weight for certain designs; *(b)* less metal removed in machining; *(c)* fewer machining operations and *(d)* harder bearing surface.

The forged shaft, on the other hand, has *(a)* Greater strength and ductility and *(b)* allows greater flexibility in design, particularly with cylinder in-line engines.

These few facts would point to the use of a cast alloy shaft providing the design of the forged shaft could be altered to have sufficient strength when cast. It so happens that crankshafts of present design, particularly those with in-line engines, cannot be so re-designed to have sufficient strength without a completely new engine, and a new in-line engine designed for cast crankshafts would probably spread the center distances of the cylinders to such a length as to reduce body space or require longer wheel base, thus losing the cost advantages of the cast shaft.

Piston Pins (Bar Vs. Tubing)

Piston pins are all carburized and made from open-hearth steel, but of five different compositions: Car 1 uses a straight carbon X-1020, Rockwell C-60 hard; Cars 3 and 4 use manganese-sulphur X-1314, C-60 or file hard; Car 5 uses a 0.90% manganese, high sulphur S.A.E. 1115, scleroscope 80; Car 6 a 0.35% chromium, low carbon steel, scleroscope 80; while Car 2 favors nickel-molybdenun, 4615, scleroscope 80.

Not alone are there five different analyses but a tubing is used by Car 6 where all others use bar stock. This difference and the different analyses are due to design requirements, different methods of processing, different accounting and carburizing and hardening methods.

Design varies in minor ways, but it is not likely, with one exception, that either the designs or loadings dictate the steel analysis. All pins must have an extremely hard surface to prevent wear, be free from soft spots, and have sufficient strength. However, strength can be obtained more cheaply by varying outside diameter and wall thickness than by steel analysis. (Often times a certain design cannot be economically changed and it is desirable to continue with a more expensive material.)

The question of tubing versus bar stock for piston pins is a matter of processing, and the relative economy of the two materials is the deciding factor. A plant already equipped to handle tubing in large production would need new machinery to drill piston pins made from bars, and the saving from cheaper bar stock might be so small that it would not offset the fixed charges and return a suitable profit on the cost of the new machinery. On the other hand, a plant not already equipped, or with obsolete tubing equipment, could undoubtedly do better with bar stock, not alone because of the comparison of cost of drilling and tubing, but also because of carburizing costs. All piston pins are kept soft on the inside; some method of preventing carbon penetration on the inside of the tubing must be used and this increases cost and must be considered in determining stock size.

The relative merits of tubing and bar stock for such properties as strength, wall thickness tolerances, decarburization or grain structure are not considered important in the decision.

Again, the different analyses used for piston pins, with one exception, are due to the last two reasons mentioned, namely, different accounting methods and carburizing and hardening practice.

The weight of bar steel in piston pins for an eight cylinder car is about 4 lb., so the greatest difference in cost per car is one cent for the material cited. Either the high manganese or the high sulphur steels will drill faster than the straight carbon type. At the Packard plant this difference in man time is about eight seconds per car. Again arises the accounting practice to determine which is the more economical practice.

Soft spots in piston pins have undoubtedly occurred in most plants, and as hardness is one of the most important properties of these parts, considerable thought has been spent to get it. High manganese and chromium help greatly in this respect and undoubtedly this fact has dictated the use of such alloy steels. Soft spots may often be controlled by certain carburizing and hardening practices, providing a "normal" steel is obtained, in which case the high manganese is not needed. It should be pointed out that in no case is the manganese below 0.70%, except where other alloy is present.

Camshafts (Carburized Vs. Cast)

Camshafts are made from two materials. Cars 1, 3 and 5 use 1020, carburized, scleroscope 75 or 80; whereas Cars 2, 4 and 6 favor a cast alloy with chilled or hardened cams and bearings tested to scleroscope 75, file hard, or Brinell 418 respectively.

Carburized camshafts have been used for many years and without service failures, so that any departure from this practice must have been dictated by costs. (This statement is not intended to detract from cast camshafts.) If cast camshafts are cheaper, "Why are they not used by all companies?" To answer this logical question we must again consider available machines, heat treating equipment and accounting methods. This has recently been done at our plant and the costs were not far apart. This is due to late equipment purchased for both machining and carburizing, and also because in considering the cast shaft the new machinery must be written off over a definite number of cars. This number is open to question and could change the decision from one method to the other, so in this case business judgment must decide.

Transmission Gears

Transmission gear steels would require several papers of this size to cover adequately the reasons for their selection, but this paper would not be complete without at least showing what is being used and the table does this.

Car 1	4620 (Ni-Mo)	Rockwell C-58
Car 2	4640 (Ni-Mo)	Rockwell C-55
Car 3	3145 (Ni-Cr)	Rockwell C-52
Car 4	6150 (Cr-V) or C-Mo (alternative)	Rockwell C-52
Car 5	3145 (Ni-Cr)	Rockwell C-52
Car 6	5135 (Cr)	Rockwell C-52

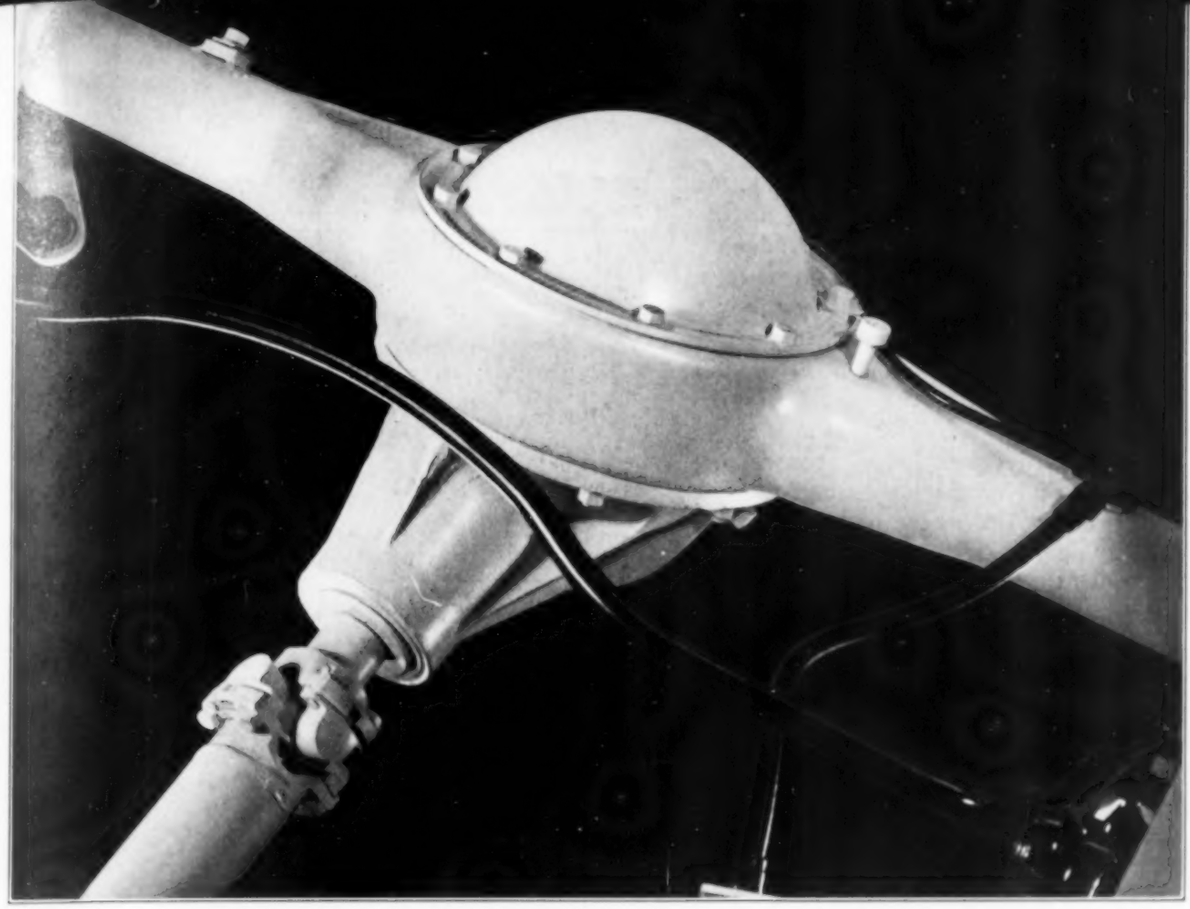
It is interesting to note that only two cars use the same analysis. No attempt will be made to give the reasons for these selections, but as you will note, some are carburized and others oil hardened, generally from cyanide or other medium giving a shallow case. It is the author's opinion that transmission gear steels of the future will have a carbon range between those in present-day carburizing and oil hardening steels, treated to give a hard surface with a more shock-resisting core, the better to withstand clashing, tooth breakage and chipping. This choice will also introduce lower alloys and consequently cheaper transmission of equal or better quality.

Transmission Drive Shaft

Transmission drive shafts in the various cars are made from two general classes of steel, the carburized type and the oil-hardened type, as dictated by design of the transmission. Certain cars have a gear turning directly on the main drive shaft and in this design a very hard material is necessary; this can best be obtained by carburizing. The alloy chosen is a matter of personal experience, based on tests, service results, past practice, shop processing, and first cost.

Car 1	1060 oil hardened forging	C-50
Car 2	4620 bar stock, carburized	Scl. 75
Car 3	3140 oil hardened forging	C-50
Car 4	3115 or C-Mo bar stock, carburized	Scl. 70
Car 5	3140 bar stock, oil quenched	C-50
Car 6	5135 oil hardened forging	C-52

Transmission drive shafts offer two acute problems, one, they must be hard to act as a roller bearing race on one end and a bearing for gears in the center and, two, they must be straightened after hardening. The hardness is not difficult to get and almost any type of steel will give



Increasing Loads Thrown on Rear Axle Shafts, Without Corresponding Increase in Size, Has Forced the Metallurgist to Heat Treat These Parts After Machining

it; however, to straighten after hardening is another problem and it is this factor that usually controls the choice. The steels listed above are the various answers, but because of the stiffness required, straight carbon or low alloys will generally rule.

Rear Axle Gear and Pinion

Rear axle gears show far greater agreement in choice than do transmissions. Nickel-molybdenum (4615 or 4620, file hard or C-60) is the choice of four companies for both gears. Car 4 favors chrome-vanadium 6115 or carbon-molybdenum (file hard). Car 6 is far different from all others, choosing the straight chromium 5130 steel at C-54 for ring gear with the chrome-vanadium 6120, carburized to C-60 for the pinion.

Rear axle gear steels have received much attention for two reasons, distortion in heat treatment and strength of teeth. Distortion has been by far the most acute problem and has, with few exceptions, dictated the material. If a quiet axle has been the rule it has been best to let well enough alone. If trouble is at hand a change may be in order, and there has been sufficient trouble in the past to have had these gears made from ½% nickel, 3½% nickel and 5% nickel, together with those shown in the table.

The strength of these gears was most completely discussed by Almen and Boegehold at the A.S.T.M. meeting in Detroit last year, and this work will begin to bear fruit when noisy axles again appear, or the inertia of past practice can be overcome. Car Number 4 is using carbon-molybdenum for ring gears and pinions and Car 6 is using a straight chromium 5130 steel for ring gears. These steels point in the direction indicated and must bear watching in the future. Lower cost alloys of medium carbon and shallow cases are sure to come.

Differential Side Gear and Pinion

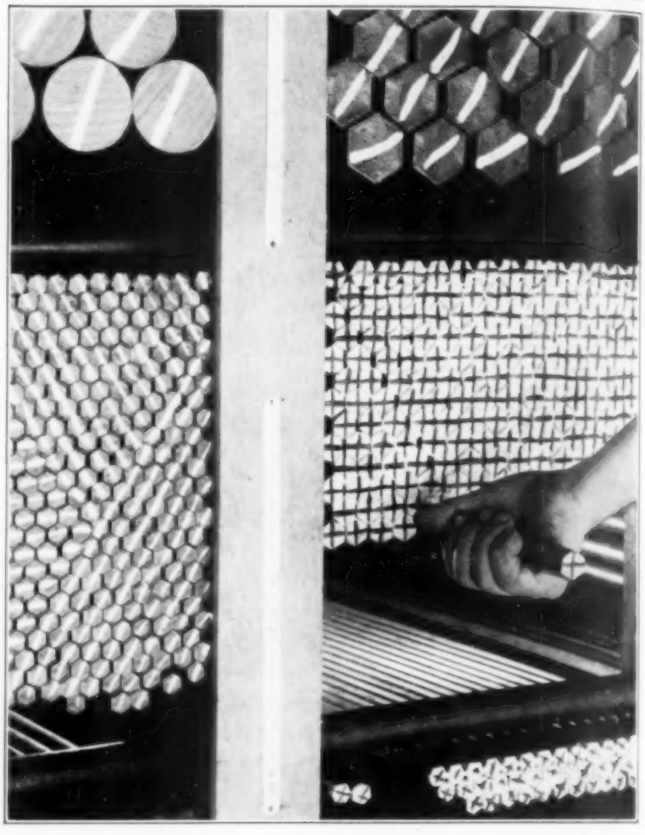
	Side Gear		Differential Pinion	
Car 1	5130	C-52	5130	C-52
Car 2	4620	75 Scl.	4620	75 Scl.
Car 3	1115	File hard	X-1015	File hard
Car 4	6135 or C-Mo	File hard	3115 or C-Mo	File hard
Car 5	1115	File hard	X-1015	File hard
Car 6	1040	514	5130	C-52

Differential side gears are forgings and pinions and are cut from bar stock; they again show

two general classes of steels used, one, the carburized type consisting of straight carbon X-1015 and 1115, nickel-molybdenum 4620, and chrome-nickel 3115 or carbon molybdenum; the other is the cyanide or oil hardened type consisting of straight carbon 1040, straight chromium 5130, and chrome-vanadium 6135 or carbon molybdenum.

The relative merits of carburizing versus cyanide or oil hardening gears is again presented on these parts. There is probably only one undisputed point on the merits of these two classes of steels — namely, that carburized gears, regardless of alloy, will give a harder surface with less tendency to pit, score or break on severely loaded teeth. The production problems of distortion, costs of machining and heat treating are much disputed and different plants will have far different answers; therefore the choice between carburized or oil hardened gears rests with the design and processing costs of a particular plant.

Choice of alloy or a straight carbon steel in either the carburizing or oil hardening steels may be dependent upon design where some thin section or small tooth requires a high strength alloy; on the other hand, it is more probable that personal preference and lack of sufficient test or service data have governed the choice.



Bar Steel in Storage Must Be Individually Marked With Color Code for Instant Identification Throughout the Shops

Rear Axle Shaft

Car 1	Carbon-molybdenum	Brinell 400
Car 2	4140 (Cr-Mo)	Brinell 400–418
Car 3	T-1330 (C-Mn)	Brinell 363
Car 4	Carbon-molybdenum	Brinell 418
Car 5	T-1330 (C-Mn)	Brinell 340
Car 6	1040 (Carbon)	Brinell 302

Choice is almost entirely dictated by the design of the shaft and the load to which it is subjected. This shaft is one of the few parts in the car in which processing costs do not greatly affect the choice of the steel. Rear axles have changed in the last few years from shafts heat treated before machining to others heat treated after machining. This change has been necessary because of the largely increased stress on these parts, without a corresponding increase in size; any change in alloy without a change in processing and improvement by heat treating would not have answered the need.

Composition chosen should depend on the strength and ductility needed. Required strength is a fairly easy figure to arrive at through service and test results; a ductility figure is more uncertain and the different compositions chosen must be based on this property. There will be little difference in tensile strength between straight carbon 1040 and chrome-molybdenum 4140 at a suitable Brinell hardness but the ductility can vary greatly. What ductility is necessary varies with individual ideas but in all cases more ductility is probably asked for than is actually needed. As the lower alloys and straight carbon steels are improved in quality and uniformity there will be a marked trend towards their use in rear axle shafts.

Steering Knuckle

The steering knuckles are in all cases forged from an alloy steel either water or oil quenched and held at about the same Brinell hardness (241 to 302). Cars 1, 3 and 5 utilize T-1330 or T-1340,

(high manganese), Car 2 uses 4130 (Cr-Mo), Car 4 either 3140 or carbon-molybdenum, and Car 6 uses 5130 (straight chromium).

The choice of steel for steering knuckles is primarily based on service results. Because of the seriousness of failure, it would not be surprising to see a tendency for high alloys, but the facts do not show this tendency. This means that the design is overly safe; no one has every heard of a knuckle failure that was not due to an overheated forging or some other equally obvious manufacturing defect.

Ductility in steering knuckles is of extreme importance for two reasons. First, the design necessarily puts the maximum stress at the junction of the wheel spindle and the main body, which is at best only a fairly large radius, and as notch effect is less noticeable on ductile materials a fairly soft material is chosen. Second, sharp blows are frequently given to steering knuckles when obstructions are hit. Without good ductility the spindle would break off; as it is, the piece bends and no serious accident occurs.

A steering knuckle is of odd shape and requires a considerable amount of accurate machining; therefore it is not practical to heat treat after machining, and the steel will be chosen to have good machinability.

While the ductility necessary, together with the best machinability, should decide, these properties are not always appraised the same in different plants, and this accounts for the difference in alloy steels in use.

Steering Knuckle Pin

Steering knuckle pins in all cars are carburized from bar stock, with the steel composition varying from a straight carbon up through the nickel-molybdenum. They must be hard to prevent wear and must have excellent fatigue resistance.

Steering knuckle pins as a rule operate in bronze bushings, so it is not likely that the surface hardness obtained on a straight carbon steel or an alloy steel would show any difference in wear in this type of service.

These parts fortunately are of a very simple design — usually a straight pin with a hole through for lubrication — and have no serious grooves or other sharp corners to produce notch effect. As a result, the carburized parts have the highest fatigue limit available and make for long life. Certain pins do have notches and are kept soft at these places to prevent failure.

Car 1	3115	(Ni-Cr)	C-60
Car 2	4620	(Ni-Mo)	70 Scleroscope
Car 3	X-1314	(Free machining)	C-60
Car 4	4620 or C-Mo	(Ni-Mo)	File hard
Car 5	X-1015	(Free machining)	C-60
Car 6	6120	(Cr-V)	File hard

The composition chosen should be such as to give the necessary fatigue limit for the stress imposed. The higher the tensile strength the higher the fatigue limit, so a steel should be chosen with sufficiently high properties to prevent failure. It is questionable, however, whether any of the designs now in production are so sensitive as to show the difference between straight carbon steel and alloy steel, if such is used.

William H. Graves, ASMember, the author, says this paper could not have been written without data, criticism and suggestions from many metallurgists in the Detroit district, but this discounts the information he himself has acquired at the University of Michigan and during 17 years with Packard Motor Car Co.

Steering Worm

Steering worms in the different cars are made from nickel-molybdenum or straight chromium steel bar stock. Cars 3 and 5 use nickel-molybdenum 4615 carburized file hard. The others use straight chromium 5130 or 5135, hardened from cyanide to C-54, C-56 or file hard. This condition exists probably because there are two large producers of steering gears who have chosen the materials listed above and certainly with good reason. The automobile companies in turn have followed the lead regardless of the fact that they make their own steering gears. This is because a steering gear is of extreme importance for safety and no one wishes to take chances on a change of this type.

The alloy chosen is open to question, and in the case of the carburized gears there is no question that some of the lower alloys such as chrome-nickel, straight chromium, high manganese or carbon-molybdenum could be tried. For the gear hardened from cyanide the lower cost alloys also offer possibilities.

Quenching Practice

Steel for automobile parts is often selected to meet a certain quenching medium, and while this has not been discussed under each individual piece, it does play an important part. Forgings which are quenched and drawn previous to machining are frequently heat treated in a so-called "forge shop heat treat." These departments are usually equipped for both water and oil quenching but better prepared for one medium than the other. Thus a steel for certain parts made in great quantity, such as a steering knuckle must be chosen to quench in the available medium.

If oil rather than water is preferred, either a higher carbon or higher alloy must be used to get the full physical properties. With a water quench, lower carbons and lower alloys can be used for the same properties, but the big objection is quenching cracks which all too often appear. Oil quenching, on the other hand, does not get all possible from the steel, and to get surface hardness, alloys are necessary.

Machined parts are generally, but not always, quenched in oil, for three main reasons, *(a)* and most important is less distortion, *(b)* shallow hardening and, *(c)* freedom from cracks. Shallow hardening is often desired to aid in straightening and to avoid distortion. Uniformly shallow hardening is more certain with oil quenching steels than with water quenching steels.

Cracks are always a source of trouble in water quenching machined pieces, usually at sharp corners and changes in sections. It is most difficult to hold the chemistry and grain structure of a water-quenching steel to sufficiently close limits to avoid them. The safest way out is alloy and oil.

Packard Front End; Stainless Steel Radiator Grille and Body Trim, Spring Steel Bumpers, Chromium Plated

High Alloys Vs. Low Alloys

The above discussion points out that high alloys are not commonly used. It also presents the view that lower alloys and straight carbon steels will be more largely used in the near future. This is intentional and is due to the improved quality of all steels from the standpoint of better physical properties and greater uniformity in composition and grain size, which results in a better finished product and fewer problems through the processing departments.

This statement is made in the face of the fact that automobile design is still tending towards greater horsepower and less weight, which in the past has been particularly responsible for alloy steel development.

In a few cases the difference in cost between two steels or alternative designs has been given to point out certain working tools. If we consider 20 parts, including those mentioned together with valves, chassis springs, and important bolts, omitting crankshaft and camshaft, and figure the difference in cost between the cheapest and most expensive steel in each case, we arrive at a figure of about $1.60 per car. This is not great considering the different designs and manufacturing processes, but based on the 1936 estimated production of 4,500,000 passenger cars we get $7,200,000 as the figure automobile metallurgists are dealing with on only 20 parts.

Non-Ferrous Melting

by H. W. Brownsdon

Condensed from Journal, Institute of Metals

METAL MELTING, FROM A QUALITY POINT of view, involves the prevention or causation of reactions that lead to changes in composition, and the required control of composition involves many factors which may conveniently be grouped under the headings raw material, contamination, and refining during melting.

Most of the commonly used virgin metals are available in a relatively pure condition, but danger from a quality point of view may easily be lurking in constituents present only in the smallest quantities. While there are many good reasons for expressing the purity as, say, 99.99%, it would be much more helpful to know what the 0.01% consists of and to define the purity of a metal in terms relating to the impurities present.

When dealing with the question of impurities as affecting quality, the purpose for which the metal or alloy is required must be kept clearly in mind, and an impurity which may be harmful for certain applications may be beneficial for others. Likewise, the effect of small quantities of impurities must not be judged solely from their individual behavior, but also from their effect on the others.

The use of scrap, an economic necessity, still further complicates the problems involved. The word "scrap" implies something inferior; this is unfortunate, in spite of its being frequently the case, for by observing greater care during handling and melting many objections raised against its use would disappear. A classic example is Professor Hutton's War-time manufacture of nickel-silver entirely from scrap on the scale of one ton per day. He obtained remarkable ductility and quality, despite the sensitiveness of this alloy to impurities, by installing a scrap laundry, with tumbling barrels and centrifugals, and by rigid scrap picking and inspection.

Oxygen from the air and water vapor and SO_2 from the furnace gases have been common sources of contamination. Protective slags and electric heat are the usual preventives, but gases in metals still are a cause of serious troubles. While some of the effects of gaseous impurities on metals are known, the position will not be clear until gas-free standards are available for bases for comparison.

Problems involved in the production of a high quality melt have much in parallel with those faced by the surgeon or physician when attempting to cure human ills and diseases. The melting pot is the operating table of the metallurgist, and it is there that he has to display his skill in curing the molten metals of their inherited or acquired diseases. Copper may suffer from chronic hydrogen, bismuth, or oxide contamination; nickel from gas, sulphur, and lead poisoning; aluminum from the ill effects of a humid climate. Besides these inherited diseases carried into the melting pot, they may become further infected during the melting process. Melting need not be an entirely surgical operation, for in some cases medicinal treatment may be preferable and the ill effects of contamination countered by suitably chosen antidotes. Once contracted the diseases may prove incurable, and then, as always, prevention is better than cure.

In some respects the difficulties to be overcome by the metallurgist are greater than those which the surgeon or physician has to face. Diseases in molten metals more or less affect the whole mass, and there may be no visual evidence of their presence or of the success or otherwise of any operations performed. The fact that metals are opaque draws an impenetrable veil over what is happening in the melting pot. Perhaps it is well for our peace of mind that it should be so!

Aside from the desirability of metal free from oxide and dissolved gases, the advantages of a fine over a coarse crystal structure in either chill or sand castings are fully recognized. While the macrostructure of the casting can to some extent be controlled by casting conditions, a similar, and in many cases more complete, grain refinement can be obtained by suitable additions to the molten metal before casting. (Zinc is an excellent example of a metal which tends to solidify in the form of large crystals and in which a fine macrostructure is encouraged by small additions of such metals as magnesium and lithium.) In such cases the added elements are generally of very low solubility in the melt, or they form compounds of high melting point. The effect may reveal itself to a more marked degree after cold working and annealing.

An explanation may be based on the assumption that small nuclei of insoluble compounds are formed in the molten metal before general solidification takes place. As with all additions, some definite change in properties results, and in the case of zinc, for example, it would be more correct to attribute the result to the formation of an alloy rather than to the production of a fine grain in pure zinc.

In melting certain metals and alloys stress is sometimes laid on the advisability of rapid melting, or of superheating the metal to a certain temperature. While such procedures may be of some economic advantage, their importance is dependent on other considerations and they may have no marked intrinsic values in themselves. When melting under reduced pressure it may in fact be better to bring the metal to the melting point more slowly. The degree of superheat can only be considered in relation to the metal and the conditions of melting, keeping in mind the effect of temperature on gas absorption, viscosity, volatility and possible reactions.

City gas containing 60% methane is used without drying or any other preparation. A certain amount of burned furnace gas infiltrates at discharge opening and this prevents the deposition of excessive soot in retort or on work. Depth of case varies with furnace temperature and time in transit

SOME TIME AGO WE WERE GIVEN A MASS PRODUCTION job of carburizing small uniform parts to a closely controlled case depth of 0.008 to 0.010 in. The parts were shake-proof tapping screws, used to fasten the soil pan under automobile engines. Such work indicates the desirability of continuous carburizing rather than batch type carburizing, in order to insure maximum control and duplication of results throughout millions of pieces.

After a careful survey of the problem we decided that the maximum of control and reproducibility in operation could be obtained with a rotating horizontal carburizing retort. This retort has spiral ribs on its inner surface for advancing the work through the furnace and longitudinal ribs for continually turning over the parts and changing their relative positions while in transit through the heating and carburizing zones of the retort.

As a carburizing medium in this type of rotary furnace gas is especially suitable, since it does not interfere with the work or introduce any handling problems which a solid carburizer might. More important, it is controllable as to carburizing efficiency, rate of flow, pressure, and availability. Low pressure city gas was found to be entirely satisfactory as received without any conditioning, control of moisture not even being necessary due to its high methane content.

The slight tumbling received by the parts while going through this furnace is an aid to gas carburizing, since it prevents the parts from being coated with any soot which might form in case the carburizing gas for any reason should get out of balance, and also

By John A. Comstock
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prevents the formation of a stagnant film of gas on the work. Both of these conditions are ruinous to uniformity in the carburized case.

Furnace Construction

A rotary retort furnace similar to the one described has been on the market for years and has been very successful as a continuous reheater of small parts for hardening. It gives very uniform and satisfactory results. It remained only to adapt this standard furnace to the carburizing job, since the temperature required was not enough greater than that for hardening (for which the original furnace was designed) to require any fundamental changes. About a year ago such a furnace was designed, built by American Gas Furnace Co., and put into operation on the carburizing of tapping screws at the main plant of the Illinois Tool Works.

As revised for carburizing the retort is fitted with an automatic trap door on the lower end, thus emptying the advancing charge little by little through the combustion chamber into a chute leading into the quench. A special cover was also made for the charging hopper; the cover is removed at intervals when work is to be fed, then replaced to keep the carburizing gas enclosed except during these brief intervals. This cover is fitted with a vent and valve for controlling the exit of the carburizing gas at all other times. The city gas itself is fed into the retort at the center of the plate covering the discharge end of the retort; the gas is caused to travel against the flow of the work and out through the above-mentioned vent in the cover of the charging hopper. A manometer in the gas line shows the rate of flow of carburizing gas, and this rate is controlled by a valve where the gas enters the retort; 25 to 50 cu.ft. of gas per hr. is required.

Before Becoming Metallurgist for Illinois Tool Works, John A. Comstock was with Peoples Gas Light and Coke Co., where he acquired a certain fondness for gas as a heat treating medium. His B.S. in Met. Eng. is from University of Illinois (1923). From 1927 on he was secretary-treasurer of the Chicago Chapter, A.S.M., for several terms, giving generously of his time and efforts to that leading group

The retort is a high nickel-chromium casting, 10 in. inside diameter, and 6 ft. 3 in. long. The driving mechanism has a variable speed control, thus regulating the rate at which the work is advanced through the furnace. It averages about 1 r.p.m., thus putting through the work in 25 to 30 min. Temperature is controlled automatically in two zones, the heating zone and the carburizing zone. The analysis of steel used is suitable for direct quenching into water from a carburizing heat of 1750° F.

Approximately 300 lb. of screws per hr. are carburized in this furnace. About 150 lb. is fed every 30 min. on time signal. The operator first extinguishes the flame at the gas exit by smothering it, then removes the feed hopper cover and steps aside while he flashes the gas in the hopper with a torch provided. After this flash he is free to throw in the previously prepared quantity of screws, replace the cover, and relight the gas vent. Another charge is then made ready for the next loading when the automatic time signal again operates.

Typical analysis of the gas, in per cent by volume, is as follows, (nitrogen by difference).

Gas	At Inlet	At Outlet
CH_4	64.3	30.9
H_2	22.0	46.9
CO	5.6	9.3
CO_2	1.1	1.2
O_2	1.5	1.4
N_2	5.5	10.3
H_2O	0.8	1.4

For approximately one-quarter of each revolution of the retort the trap door at its discharge end is either open or partly so, thus allowing a limited amount of products from the combustion chamber outside the retort to enter the retort. This infiltering furnace gas enters in close proximity to the place where fresh carburizing gas is admitted. Its analysis is typically 12% CO_2 with the balance nitrogen and water vapor, and the extent of this dilution is indicated by increase in the percentages of H_2O and N_2 at the out-

let. Addition of such a gas in limited amounts and at regular intervals serves not only to dilute the rich city gas, high in methane, but to prevent the formation of excess quantities of soot according to the reactions:

$$CO_2 + CH_4 \rightarrow 2CO + 2H_2$$
$$CO_2 + C \rightarrow 2CO$$

Comparing the analyses of the city gas at inlet and the spent gas at outlet, a marked decrease in CH_4 and attendant increase in H_2 is noted. This indicates the cracking of the hydrocarbons as follows:

$$CH_4 \rightarrow C + 2H_2$$

There is little carbon or soot *deposited* in the furnace or on the work, due to the fact that the gas is free to pass through the retort and out, carrying with it any excess carbon still in suspension. This can be observed at the gas outlet, and is an aid in regulating the amount of raw gas so as to avoid the point where free carbon is formed in the retort.

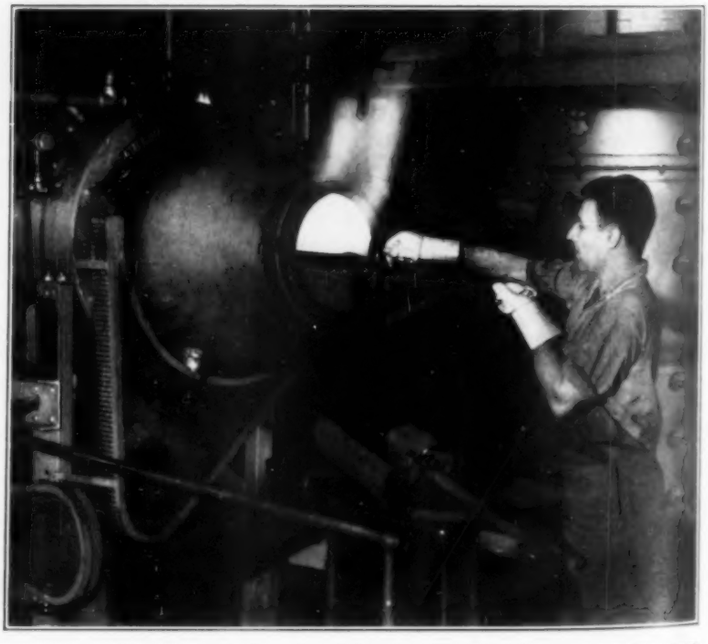
The presence of water vapor in the gas inhibits the cracking of the hydrocarbons to a certain degree, as evidenced by the high residual CH_4 and the H_2O content in the outlet gas (see the analyses quoted on page 45).

Summary of Process

The features of such equipment and the carburizing procedure as outlined above can be briefly enumerated as follows:

1. Continuous carburizing in rotating retort, the work slowly rolling through the heating and carburizing zones and falling by gravity through a gas-filled chute into the quench.
2. Undried, low pressure city gas (60% methane) as the carburizing medium.
3. Dilution of carburizing gas with products of combustion, the ratio of raw city gas to products of combustion controlled by a valve in the raw city gas inlet line.
4. Depth of case controlled by speed of retort and temperature of furnace.
5. Concentration of carbon in case controlled by ratio of raw city gas to products of combustion.

Photomicrograph at 50 Diameters Showing Cross-Section of Carburized Screw Thread, as Quenched. Depth of case required is 0.008 to 0.010 in.



Operator Has Removed Door Which Normally Closes Retort, Flashed the Gas Trapped Inside With a Torch, and Is Now Loading 75 Lb. of Screws Into the Charge Hopper. After the second scoop-full is in he quickly replaces the hopper door and lights gas which emerges from the vent pipe

Cold Finished Bars

flats, shafting, shapes

Cold drawn bars, so widely used for their clean surface, their improved physical properties, machinability and heat treatability, and their close accuracy in size and shape comprise only one of five methods of cold finishing. This article is one prepared for the 1936 Edition of the A.S.M. Handbook.

COLD FINISHING FIRST APPEARED IN 1857 IN THE form of a cold rolling process for wrought iron, invented and patented by Bernard Lauth. Later the same process was used on steel, primarily for shafting for power transmission units, machinery and agricultural implements.

Cold rolling, as a means of cold finishing, gradually lost ground after developments in the wire industry disclosed that drawing the larger wire sizes through dies produced practically the same improved physical properties. Finally, about 1890, the two processes came to be considered interchangeable from the standpoint of effect, and although cold rolling was never replaced completely and is still used for certain purposes such as wide flats, the principal method of cold finishing steel today is by cold drawing.

The growth of the industry during the past 30 years is largely attributed to the rapid development of the automotive, electrical equipment and machinery industries. The producers of cold finished steels have kept pace with the progress of these industries by providing standard and special analysis steels in various finishes and treatments to satisfy a diversified range of requirements.

In the present state of the art, cold finishing of steel, generally used for bars and shafting, may be defined as the process of reducing their cross-sectional area, without any heating, by one of five methods: (1) Cold rolling; (2) cold drawing; (3) cold drawing and grinding; (4) turning and polishing; (5) turning and grinding.

Cold finishing is employed principally for one or more of the following reasons: *(a)* Unusually accurate size; *(b)* smooth or bright surface finish; *(c)* improved physical properties; *(d)* better machinability.

Of the five methods listed above, items (2) cold drawing and (4) turning and polishing produce the largest tonnages, with cold drawing occupying the foremost position. This is true principally because it is applicable to a wide range of sizes and a large variety of shapes, such as rounds, squares, flats, hexagons, standard and special sections.

The selection of the method to be used is governed either by economic reasons, shape or size of the section, or the necessity to meet requirements characteristic for one of the methods. For example, the usual practice is to cold draw smaller sizes of rounds up to about 3¾ in. and turn the larger sizes. Whenever a superior finish or size accuracy is required the material is ground. Turned and polished bars, usually over 1⅛ in., are furnished where hot rolled phys-

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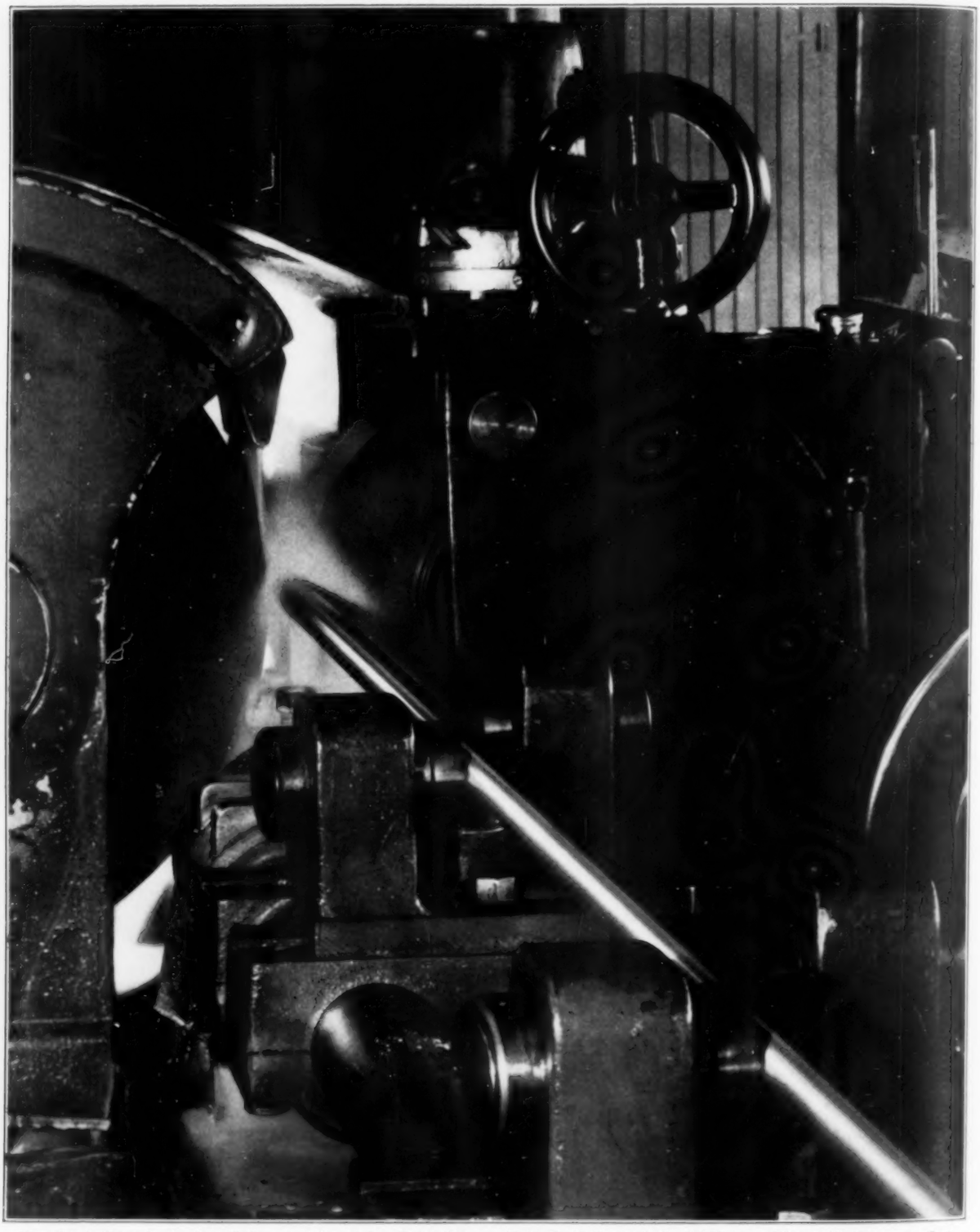


Standard Manufacturing Tolerance for 1-In. Cold Drawn Soft Steel Rounds Is 0.002 In.; Closer Tolerances Can Be Produced, Particularly on Ground Bars. (Photo by Margaret Bourke-White; courtesy Ludlum Steel Co.)

ical properties and cold finished accuracy are desired plus a finish that is reasonably free from the normal surface imperfections that are found on hot rolled bars.

Description of Processes

General—Since any surface defects and imperfections present in the hot rolled product are accentuated by cold drawing or cold rolling, it is necessary that the preparation of the hot rolled material for such purposes be surrounded with many precautions. In fact, the surface requirements of hot rolled bars for cold finishing purposes are similar to those imposed on forging steel — that is, the surface must be substantially free from seams, pits and excessive scale.

Prior to cold drawing, the hot rolled material is usually immersed in a bath of 4 to 8% sulphuric acid at a temperature of about 150° F. until the scale is completely removed. It is then washed and dipped in a lime solution, which neutralizes any acid that may be remaining on the bars and also serves as a rust preventive and a lubricant in the drawing dies. Drawing through a die, straightening, and then cutting to length complete the sequence of operations.

Cold Rolling — When cold finishing by cold rolling the hot rolled bars, cleaned of scale, are passed repeatedly through a set of rolls, thereby subjecting the material to a light reduction in each pass, until the final size is obtained. Cold rolling imparts a bright surface finish, accurate size, and an appreciable increase in the tensile strength with an even greater increase in the yield point.

Cold Drawing — In this method, a hot rolled bar of practically any shape, after having been cleaned of scale, is pointed and pulled cold through a die whose bore section is generally $\frac{1}{32}$ in. to $\frac{1}{16}$ in. smaller than the dimension or thickness of the original bar. However, the amount of draft, so-called, may be varied from 1/64 in. to $\frac{1}{8}$ in., depending upon the analysis of the material being drawn, the hot rolled size, and the physical properties desired. The effects of cold drawing are similar to cold rolling, the final product having a bright surface finish and accurate size, with its tensile strength and, particularly, the yield point and proportional limit increased materially.

Cold Drawing and Grinding — For purposes where the size accuracy, surface finish, straightness or concentricity imparted by cold drawing or turning and polishing are inadequate, grinding is resorted to after cold drawing. The physical properties of this type of cold finished product remain unchanged from those of the cold drawn bar.

Turning and Polishing — Whereas cold drawing reduces the cross-sectional area by subjecting the bar to compressive and elongating forces, turning and polishing accomplishes the same end by turning $\frac{1}{16}$ to $\frac{3}{16}$ in. from the diameter, depending on the bar size, usually followed by a pass through a combination straightening and polishing machine. By this method, close accuracy as to size is obtained — similar in degree to that of a cold drawn bar — but the finish of the surface is somewhat brighter, and surface decarburization, surface seams, and other minor defects in the hot rolled bar which are not affected by the cold drawing operation are removed. Since the steel has not been cold worked in any appreciable manner, the physical properties of the hot rolled bar follow through to the turned and polished product.

Turning and Grinding — In this process the hot rolled bar has its rough and imperfect surface removed by turning and it is then ground, usually in the centerless type of machine. This results in a product whose finish and characteristics are similar to cold drawn and ground material, except that the hot rolled physical properties have not been changed.

Properties of the Material

Size and Finish — From the above discussion, the various methods of cold-finishing may be grouped as follows according to superiority of size and finish:

	Accuracy of Size	Quality of Finish
Turning and grinding	First	First
Cold drawing and grinding	First	First
Turning and polishing	Second	Second
Cold drawing	Second	Third
Cold rolling	Third	Third

One of the outstanding advantages of cold-finished steel is the close tolerances that can be maintained in size. Standard manufacturing tolerances have been agreed upon, and a printed list showing the limits for various sizes and shapes is available from any manufacturer or large jobber. For cold finished steel rounds and shafting the undersize variation is 0.002 in. for 1 in. rounds or smaller, and it increases with size of bar to 0.006 in. for a bar over 6 in. and up to 7 in. This is for 0.30% carbon steel; harder

steels (up to 0.50% carbon) have undersize tolerances increased from 0.001 to 0.002 in. Tolerances on flats depend on thickness, relation of thickness to width, and carbon content.

The degree of accuracy produced in shapes and special sections is comparable to the standard tolerances for hexagons, squares and flats of the same cross-sectional area and hardness. Closer size tolerances can be produced when necessary, particularly on ground rounds.

Cold finished bars are straightened commercially to within $\frac{1}{32}$ in. in 5 ft. Rounds for shafting are held considerably closer; even better straightness requirements can be met by special processing in straightening.

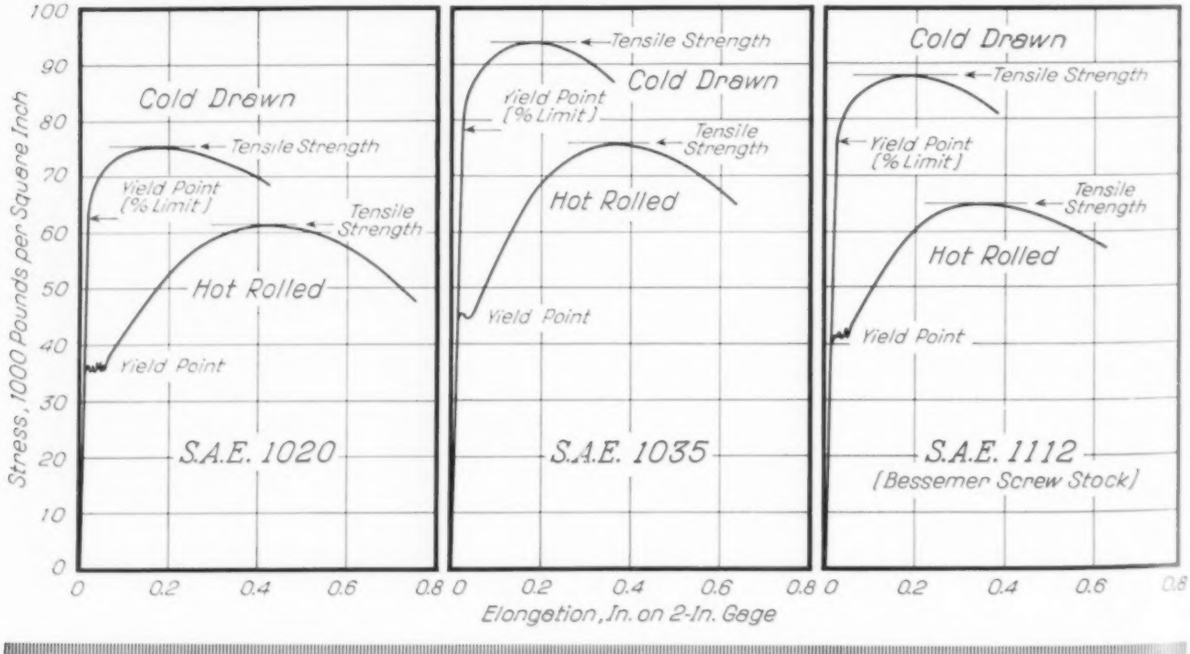
Physical Properties — The adjoining tabulation represents average physical properties that result when hot rolled bars of the analyses listed are cold drawn one pass (about $\frac{1}{32}$ to $\frac{1}{16}$ in. reduction on diameter). The data presented are general in nature, and should therefore not be interpreted as values necessarily obtainable in all cases, sizes, and conditions.

Stress-strain diagrams of bars of three common cold drawn grades give a general idea of the marked increase in tensile strength and particularly yield point which occurs in this process. Tensile strength is not raised as much as the yield point (or proportional limit) but since permanent distortion is a function of the yield point rather than of tensile strength, this effect upon cold drawn materials is of vital importance in its application to machinery. The increase in yield point is accompanied by a decrease in elongation and reduction in area, but not enough to materially interfere with the use of such materials where the higher yield points are necessary.

A cold drawn bar of properties intermediate between the extremes in yield point and elongation can be obtained by annealing or normalizing treatments. Of late, some attention is being given to the effect of "strain drawing" or "stress relieving" cold drawn bars by heating them at temperatures in the neighborhood of 500° and 600° F. Such low temperature treatments have practically no deleterious effect on the size or finish, and are instrumental in boosting the tensile strength and yield point without sacrificing ductility to any great extent.

Because of the desirable physical properties, cold drawn bar stock is often substituted for heat treated bars, since it is not as costly, and is easier to machine. In other applications where it is desired to have heat treated properties along with

Stress-Strain Diagrams for Three Common Types of Mild Steel Show That Cold Drawing Raises the Tensile Strength and Especially the Yield Point and Reduces the Elongation (and Reduction of Area)



Average Physical Properties of Cold Drawn Bars
½ In. to 2 In. Diameter, 0.505-In. Test Specimens, 2 In. Gage Length

SAE Grade	Tensile Strength	Yield Point	Elongation in 2 In.	Reduction of Area	Brinell
1010	67,000	55,000	25.0	57.0	137
1015	71,000	60,300	22.0	55.0	149
1020	75,000	63,700	20.0	52.0	156
1025	80,000	68,000	18.5	50.0	163
1030	87,000	73,900	17.5	48.0	179
1035	92,000	78,200	17.0	45.0	187
1040	97,000	82,400	16.0	40.0	197
1045	102,000	86,700	15.0	35.0	207
1112	87,000	73,900	17.0	45.0	183
1120	78,000	66,300	19.5	49.0	159
X-1314	80,000	68,000	19.0	51.0	163
X-1315	82,000	70,100	18.5	50.0	167
X-1330	98,000	83,300	18.0	40.0	201
X-1335	105,000	89,200	16.0	35.0	217
X-1340	112,000	95,200	14.0	30.0	223

the more accurate size tolerances, hot rolled bars may be heat treated in accordance with the user's requirements and then turned and ground, or turned and polished. The manufacture of highly machined parts from cold drawn stock, to be subsequently case hardened or otherwise heat treated, is wide spread owing to its superior machinability and response to heat treatment.

Machinability — Another very important advantage of cold finished material is its superior machinability as compared with a hot rolled product. This depends upon several features including the fact that cold work induces an improved machining quality in the steel itself. Furthermore if steel is cold finished by any of the five standard methods, it performs better in the machine shop because it is free from hot rolled scale and is accurate in size and has a greater degree of straightness. These advantages are recognized generally by buyers interested in machining quality as indicated by the large percentage of cold finished steels used, particularly for automatic screw machine work where the machining requirements are most exacting and severe.

Inspection and Testing

To insure a cold finished product that will perform satisfactorily for the diversified application of its users, it is necessary for the steel maker to furnish metal of the very highest quality. As previously mentioned, the standards of practice adopted for steel making, preparation and inspection of semi finished sections, and inspection of the final bar are the equivalent of those enforced for forging steels.

Precautions are taken during the making and rolling of the steel to minimize chemical irregularity, seams, pipe and other defects, surface or internal. After cold finishing, the bars are inspected closely for these same defects, as well as checked for size, straightness and out-of-round.

Uses of cold finished steels have become so wide-spread that their applications are too numerous to attempt to cover completely. The more common uses are for spark plug shells, radio speaker cores, bolts, nuts and screws, gears and pinions, parts for typewriters, sewing machines, cash registers, and other light machinery, chain pins and rolls for silent chains, motor and transmission power shafting, motorcycle crank axles, oil pump shafts and gears, piston pins, steering gear arms, bushings, pins and worms, tie rods, wringer rolls, gun parts and commutators. Industries such as the manufacturers of automobiles, motorcycles, sewing machines, typewriters, business machines, textile machinery, shoe machinery, agricultural implements and electric equipment are particularly large consumers.

H. W. Graham is general metallurgist for Jones and Laughlin Steel Corp. He has long been a close student of carbon steels, including the lowly bessemer screw stock and the important group of cold drawn bars, shapes and shafting

Sprayed Metal Coatings

technique and properties

A branch of metallurgic art known as metal spraying has developed far faster in Europe than in America, where until recently it has been hampered by onerous patent restrictions. Success requires the user to observe certain fundamental requirements, outlined in this paper .... Properties of the coating and cost of the operation are also given for various metals

WHEN A YOUNG MAN REACHES HIS 21ST BIRTHDAY he comes of age, and though he may have tried and studied much, his life is just beginning. So it has been with the art of metal spraying. It may not be entirely accurate to allocate 21 years to this development, but its "coming of age" is a true analogy.

In 1910 a Swiss engineer, M. V. Schoop, published three articles (one in France, one in England, and one in the United States) on a new process for metal coating. He had observed the appearance of small lead bullets after they had been fired against his garden wall, and believed that at the moment of impact an actual fusion had occurred. While this is not exactly true it gave him the idea that atomized particles of hot metal, striking a surface at sufficient velocity, would form a coherent coating.

In his first equipment a molten pot of metal was the source, and a small stream of it was broken into fine shot by a jet of air. This was patented by Schoop in the United States in 1915 (1,128,058). This proved too bulky an equipment for general use. Consequently the commercial development has utilized a "pistol" or "gun" which melts a wire as fast as it can be sprayed. This idea and the equipment were patented in the United States by Morf (1,100,602 and 1,128,175) at about the same time of Schoop's American patent, according to Henry S. Rawdon in his valuable book on "Protective Metallic Coatings."

By E. L. Mathy
First Vice-President
Victor Equipment Co.
San Francisco

In the intervening 21 years the process and equipment have been perfected largely by trial and error method. Much of the development has occurred in Europe and England, under the watchful eye of the inventor. The result is that its applications are much more widespread over there than in our own country, and a very comprehensive account is contained in a book by T. H. Turner and N. F. Budgen on "Metal Spraying," published in England.

Such equipment has, of course, been available in this country, but unfortunately for the spread of the art, most potential American users have regarded the licensing fees as being too high. We would estimate that in the last two years, since the expiration of the basic patents, at least 1500 metallizing "guns" have been sold in America — ten times as many as in the previous 20 years!

Such a rapid spread also has its dangers. The process has, in the past, sometimes fallen into the hands of promoters who advocated metal spraying for everything under the sun. They have said that the process is as simple as paint spraying, and said nothing about the careful preliminary surface preparation that is

necessary, nor the necessity that the pistol and auxiliary equipment be precisely regulated and constant in action. Likewise, in an attempt to speed up the process, guns have been built which feed a wire much too large to be adequately melted and sprayed. It will be my effort to point out some sound practices in metal spraying, as developed by many years of commercial experience with the process.

What Is Metal Spraying?

The metal spray gun is a device which feeds, automatically, a drawn wire of carefully selected diameter, through a nozzle and a circle of small, intense flames at a speed equal to the melting speed of the wire chosen.

An air-driven turbine, built into the gun, actuates a simple geared mechanism which grips the wire firmly and pushes it through the device and into the nozzle. The speed of this air turbine is adjustable to conform to the melting rate of the metal wires that can be used.

As the wire feeds into the circle of flames it is instantly melted and carried forward by the combustion gases of the gas flames into the core of an air blast. Each molten metal globule is then taken up by a stream of high pressure air and shot against the surface to be sprayed. It is estimated that these molten metal globules are traveling at approximately 30,000 ft. per min. or 300 miles per hr. The process, being a continuous one, creates a stream of finely atomized metal globules which lodge themselves into the minute crevices of the properly prepared surface we desire to cover.

From the foregoing it can be noted that the success of the application depends upon several correlated requirements. In the first place, we must supply the gun with a stream of compressed air which remains constant in pressure and volume — first, in order to maintain the desired air turbine speed and second to supply the needed volume of air to atomize and carry forward the melted metal globules. Given an air compressor of sufficient capacity and pressure regulation which remains accurate, these two requirements are easily met.

The air must be free from moisture, oil and dirt, and an air filter of a capacity of 35 cu.ft. per min. should be placed in the air line at a point as near as practicable to the "metalizer," as the gun is sometimes called. Since the preparation of the majority of surfaces which are to be sprayed requires sand blasting (as we shall see further on) it is well to have a compressor large enough for both purposes; one with a displacement of 120 cu.ft. per min. is usually quite sufficient.

The needed flames for surrounding the wire-end and melting the metal are usually produced by oxygen and acetylene, although other fuel gases can be used for the more fusible metals such as lead, tin, zinc and aluminum, if they are available without extra trouble and expense. Pressure, volume and composition of these gases must be constant, after regulation for the metal being handled. These requirements are most easily met by oxygen and acetylene in cylinders, as prepared for welding; pressure is controlled by regulators developed for welding. (For the required accuracy, the so-called two-stage pressure regulators are preferable, where one stage reduces the declining cylinder pressure to a more or less fixed figure somewhat above that required at the spray gun, and the second reduces this fairly steady pressure to the required figure with precision.)

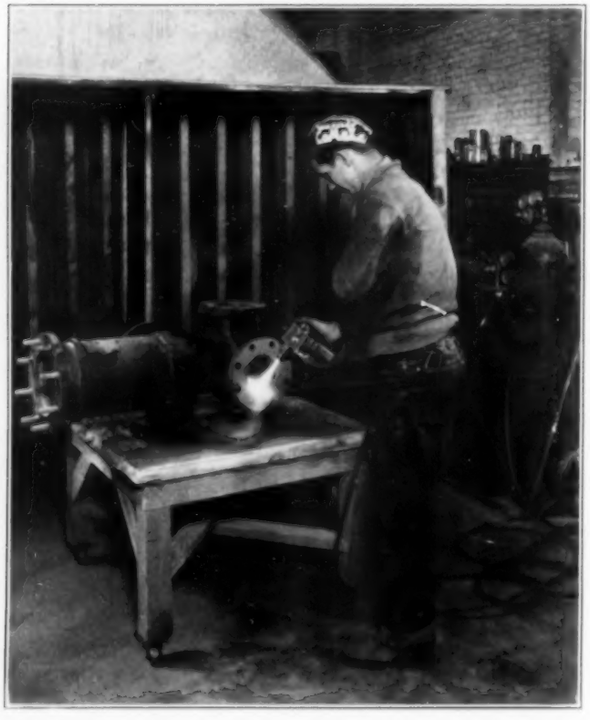
E. L. Mathy Entered the Welding and Cutting Industry in 1917. He was educated in Europe and had the good fortune to watch the first developments in metal spraying on the Continent. His travels have been extensive — developing what may be characterized as a world-wide interest in welding, cutting and spraying

Predicated upon a properly designed metallizing gun and these other easily obtainable requirements, the actual spraying is both simple and speedy and the operator needs no unusual skill beyond reasonable experience and the same degree of conscientiousness as is expected of a good welder, a dependable riveter or a careful painter.

Structure of the Metal

It would appear on casual thought that this method of developing a spray and discharging it at high velocity by an air stream would burn the metal completely. As a matter of fact, each tiny globule is doubtless oxidized on the surface, but the metal is protected more or less when it is hottest — just after melting — by the enveloping gases of balanced combustion. Its contact with air is also very brief; if the nozzle is six inches from the article being coated, the globule strikes and cools within one-thousandth of a second. Likewise there must be a proper balance between heat and speed so that the finest particles of metal do not chill and solidify into a spray of hard shot.

When these molten or plastic particles strike a surface at high velocity they spatter somewhat — or at any rate flatten out into a very thin layer. The oxide coating on the globule and on the cold surface itself is certainly broken at the center of impact, and metal-to-metal contact results in a true weld at those points. A true weld is also indicated by the very considerable tensile strength of these coatings (as described later) and by X-ray studies at the Bureau of Standards which indicated the presence of some brass or copper-zinc solid solution in a duplex coating made of pure copper and zinc alternately.



Spray Gun Melts the Proper Wire With Oxy-Acetylene Flame and Blasts Atomized Metal Against a Prepared Surface With Compressed Air. Adequate surface preparation and a conscientious workman are pre-requisites

Overlapping particles of metal will, of course, trap the oxide which has formed, and it is believed that this oxide rather than any porosity or blowholes is the real reason for the difference in specific gravity between a spray coating and the original wire.

The arrangement of the tiny, flattened particles may be likened unto the arrangement of fish scales — each plate interlocking its neighbor, overlapping the one beneath and the whole forming an armor plate which protects and preserves the material beneath.

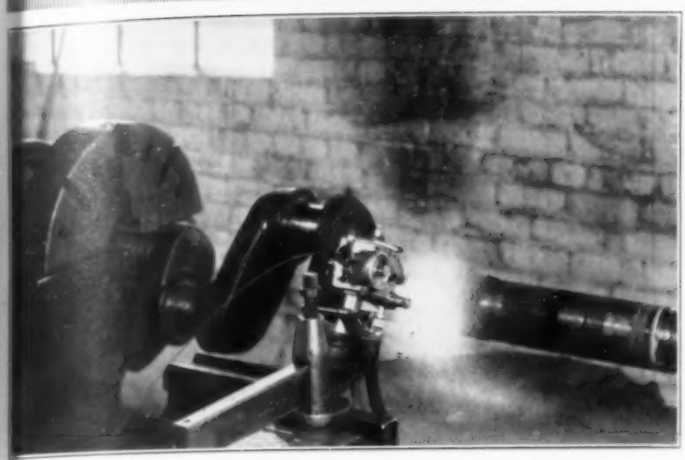
Preparation of the Surface

If anything, the preparation of the surface to be sprayed is of even greater importance than any other item of successful procedure. As pointed out previously, the spray consists of extremely fine particles of metal traveling at tremendous velocity. As these particles strike the surface they are driven into all crevices and irregularities which may be inherent in the material or created by proper preparation.

Depending upon the density of the material to be sprayed, the base may require merely perfect cleaning, such as would be the case if metal were to be sprayed on wood or cement, or require sand blasting in the case of metals. Sand blasting should be executed with properly selected sand or steel shot, as the case may warrant, and be done immediately prior to metal spraying since any subsequent collection of dust or dirt, even finger marks, will prevent proper bonding.

Assuming that we are "metallizing" a steel rod, the first coat is key-locked to the blasted surface. Under a microscope the blasted surface shows thousands of irregularities which hold the metal layer; to get it into these little crevices the metal must be atomized very finely. The coatings follow the exact outline of the surface sprayed and the second coat when sprayed has the same keyed surface offered to the first coat. Each succeeding coat is therefore securely keyed to the previous coat which in turn is keyed to the steel base by the blasting — this in addition to the incipient welding mentioned above.

There is a limit to the number of coats that



Much Thicker Coatings Can Be Sprayed on Rounds by Simple Mechanical Devices Than Will Adhere to Flat Surfaces, for the Shrinkage of Each Layer Grips the Curve Rather Than Tends to Peel

can be applied because each succeeding coat in cooling has a tendency to pull the original coat away from the steel base. For this reason we do not recommend coatings of hard metals on flat surfaces to a thickness over 0.025 in. On shafts and rounds a greater thickness can be applied, because the metal when deposited shrinks considerably, and grips the foundation more closely.

Actual manipulation of the metal spray gun is much the same as that of an ordinary paint spray gun. The spray is passed back and forth across the surface to be coated, and each pass deposits a certain thickness of metal. An average speed of manipulation with what may be called "standard, all-purpose equipment" will deposit approximately 0.003 in. of the soft metals, such as lead, tin and cadmium; 0.002 in. of zinc; 0.0015 in. of copper, bronze, and other metals having a melting point range of from 1000 to 2000° F. The metals with higher melting point, such as monel, stainless steel and carbon steel, will deposit at the rate of from 0.001 in. to 0.00125 in. per coat. These figures may be doubled when using "high speed guns" for the softer metals and "hard metal units" for the steels. As many coats as are desired can be applied with equal ease, and it is not required to wait for the "drying" of the previous coating as is the case in painting. (Limitations as to thickness have to do with the heat effect, as noted above.)

The speed of coating depends also upon the particular type of metal sprayed. An average operator can cover an area of from 30 to beyond 120 sq.ft. per hr. depending on the metal being deposited and the type of equipment used.

The table at the foot of this page gives some idea of costs. Figures do not include surface preparation or overhead. "Spraying costs per hour" include the following:

Labor (60¢ per hr.) 70% efficiency	$0.86
Acetylene ($2.75 per 100 cu.ft.) 24 cu.ft.	0.66
Oxygen ($1.20 " " " ") 25 cu.ft.	0.30
Compressed air, 30 cu.ft. per hr.	0.20
Total per spraying hour	$2.02

The selection of the metal wire depends upon the purpose to be achieved and an appreciation of the inherent quality of metals. Any metal which can be drawn into wire can be used for metal spraying but the selection necessarily depends upon what purpose the finished coating is to serve.

Properties of the Coating

Many failures in the past have been due to lack of skill, knowledge or care on the part of

Cost and Speed of Metal Spraying

Metal Sprayed	* Unit	Wire			† Total Cost per Hr.	Area Sq. Ft.	Cost per Sq. Ft.	Thickness One Coat
		B & S Gage	Lb. per Hr.	Cost				
Lead	S	10	45	8.10	10.12	120	0.084	0.0037
Lead	H.S.	10	85	15.30	17.32	120	0.145	0.007
Tin	S	10	25	17.25	19.27	120	0.16	0.0031
Zinc	H.S.	12	15	3.15	5.17	120	0.043	0.002
Cadmium	S	10	25	29.50	31.52	120	0.263	0.0025
Aluminum	S	16	1.8	1.17	3.19	60	0.054	0.0016
Copper	H.M.	12	7.7	1.31	3.33	40	0.083	0.0034
Brass	S	18	4.2	1.18	3.20	70	0.045	0.0011
Nickel silver	S	18	3.7	1.85	3.87	60	0.065	0.0012
Monel metal	S	18	1.7	1.11	3.13	30	0.11	0.0011
Soft steel	H.M.	12	4.0	0.60	2.62	40	0.066	0.0022
Hard steel	H.M.	12	4.0	0.80	2.82	40	0.071	0.0022
Stainless	H.M.	12	4.0	3.20	5.22	40	0.131	0.0022

* S = standard unit; H.S. = high speed unit; H.M. = hard metal unit
† Total cost = metal cost plus $2.02 for spraying cost (see text)
No overhead, surface preparation or finishing included

the users of this process. Consequently the thought, for instance, that a stainless steel coating would be of much use except against atmospheric attack may be received with skepticism. As a matter of fact, ample experience is available in the records of many western oil companies indicating that pump rods, shafts and plungers, sprayed with stainless steel and properly polished, are quite as resistant to corrosion and more resistant to abrasion than though made of solid stainless. Linings from 0.015 to 0.018 in. thick on the inside of pressure vessels have also satisfactorily resisted the action of hydrogen sulphide solutions and gas.

All the "hard" metals, carbon and alloy steel, as well as stainless, should be polished when spraying is complete to increase the density of the coat. On account of the difficulties of polishing flat surfaces it should be recommended that hard metal coats be confined to rods and shafts.

For tin coatings in the dairy and food industry 0.015 to 0.020 in. of metal is needed. Of zinc coatings we recommend 0.006 in. for general atmospheric conditions and 0.010 in. for salt air or salt water. For lead coatings to protect against sulphuric acid gases in blowers, fans, and ventilating equipment, we recommend 1½ lb. of lead per sq.ft. or approximately 0.015 in. thickness.

Lead and tin coatings should be wire brushed between coats to increase the density of the metallic deposit.

Finally some figures on the tensile strength and ductility of sprayed coatings are given in the table above, as determined from work done at the California Institute of Technology. The method used was to spray a thick coating on a surface, strip the coating by chemical means, and then place the resulting specimens of pure sprayed metal in an appropriate tensile machine.

Properties of Sprayed Coatings

Sprayed Coating			Metal	Pure Metal, Cast & Annealed		
Elongation in 2 In.	Ultimate Strength	Specific Gravity		Elongation in 2 In.	Ultimate Strength	Specific Gravity
1.3%	4600	6.46	Zinc	65%	16,000	7.14
1.1	4900	2.44	Aluminum	45	13,000	2.71
nil	4400	7.91	Copper	58	32,000	8.94
1.3	3300	6.95	Tin	80	3,000	7.30
1.5	1950		Lead	64	2,000	11.34
nil	3750		66-34 Brass	60	45,000	8.47

High Speed Welding with low internal stresses

by A. B. Kinzel

Condensed from British Iron & Steel Institute Symposium on Welding

A LOGICAL APPROACH, FROM THE METALLURGIST'S viewpoint, indicates at once that there are three fundamental requirements for any type of weld. First is mechanical homogeneity of the joint, frequently termed "complete fusion." This implies that the surface of the material to be joined shall form a continuous liquid solution with the molten metal, generally added from a welding rod. This does not necessarily mean *complete* liquefaction of the surface of the materials to be joined.

Consider the joining of steel plates by butt welding. If the plate is completely fused to a given depth from the original surface, the fused material from the plate forms a liquid solution with the fused material from the rod, but the actual junction between the plate and what is later considered to be weld metal takes place at that surface at which the material is between the solidus and liquidus temperatures, and rather nearer to the solidus. Thus, there would seem to be no virtue in melting an appreciable portion of the plate material. It has also been deemed necessary to melt the base metal in order to ensure that the junction surface shall be free from oxide film or inclusions originally in the steel or formed during heating.

This brings us to the first principle involved in the development of high speed, high quality autogenous welding, namely, the production of a clean junction surface on the base metal with minimum or even negligible melting of the base metal during the operation. This, in addition to attempts to overcome the limitations of heat transfer from a single oxy-acetylene flame and the metal, has recently led to three developments:

1. The use of preheating flames on the plate and scarf. *(Continued on page 90)*

Shallow Hardening

factors causing it

An extension of an article in last month's issue defining critical rate of cooling, split transformation, and rate of transformation, showing how the latter is influenced by quenching conditions, carbon and alloy content and grain size

By Francis B. Foley
Superintendent, Research Dept.
The Midvale Company
Philadelphia

IN THE ARTICLE IN LAST MONTH'S METAL PROGRESS a brief historical resumé of the hardening theory was presented, ending with a generalized statement that the hardness of steel after quenching is due to at least three factors — the allotropic transformation of gamma iron to alpha iron, the passing out of solution of carbon and the formation of iron carbide. Much light on these chemical and physical reactions in steel has recently been shed by extensive studies on the influence of the quenching rate, the temperature of the quenching medium, and the carbon and alloy content, so that a detailed account of the influence of these factors can now be given.

The first work on this phase of the problem of hardening — and which appears to be the forerunner of a number of researches reported since — was that of Portevin and Garvin in 1919. By using cylindrical specimens of various diameters and accurately measuring the rate of cooling, these investigators found that with slow rates of cooling a transformation occurred in the neighborhood of 1200° F. and resulted in a soft specimen. (The diagram Fig. 31 in their paper before the British Iron and Steel Institute in 1919 is reproduced on the next page.)

At a rather small change in cooling rate, as represented in this diagram by the difference at the center of a 13 and a 11 mm. cylindrical specimen, the upper transformation disappeared. By the change in slope of the lower part of the curves, these authors inferred that the transformation was depressed and occurred at 575° F. or below. Specimens cooled at this rate were found to be as hard as they could be made by direct quenching, and to be completely martensitic in microstructure.

From other considerations these two pioneering experimenters concluded that specimens cooled at or near this transition rate possessed *two* critical temperatures, the one at 1200° F. which they called Ar′ and a lower one at 575° F. (Ar″) or less. Regions in the steel cooled at this intermediate rate were of greater hardness than when more slowly cooled, and when examined microscopically were found to be mixtures of martensite and a dark-etching constituent commonly called "troostite."

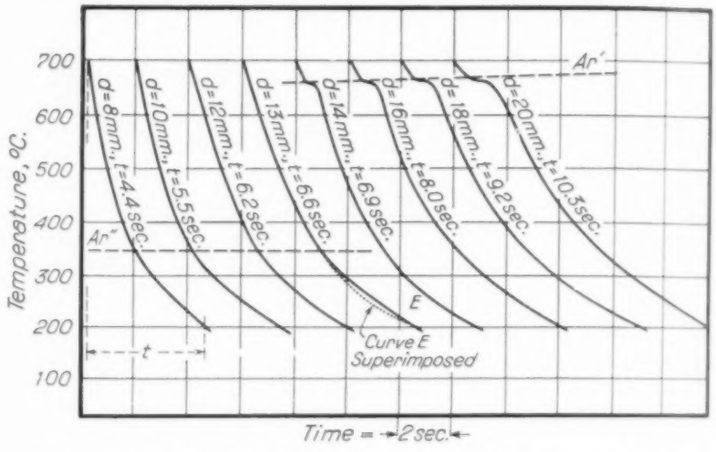
As before mentioned a still faster rate of cooling caused the higher critical temperature during cooling to disappear entirely, so that a single transformation into martensite occurred at 575° F. or below, and the maximum hardness was attained.

This work of Portevin and Garvin gave rise to the conception of a "critical rate" of cooling. Each composition of steel was then found to have its peculiar critical rate, which had to be exceeded in order to produce complete hardening. Their designation Ar′ was widely adopted for the transformation occurring at the high temperature during cooling which resulted in a sample with a much softer surface. It was accepted that hard martensite formed at the lower point Ar″. It was observed by Portevin and Garvin that the reaction time — that is, the time required to complete the higher temperature transformation — was very short, and that it required very rapid cooling to suppress it. On the other hand, the transformation from austenite direct to martensite at lower temperature took a very much longer time for its completion.

Their specimens were plain carbon steels and covered a wide range of carbon content; it was observed that the critical rate of cooling (the rate necessary to suppress the upper transformation and so to produce complete hardening) was slower for steel with about 0.85% carbon than for steels of either higher or lower carbon content. In other words, so-called eutectoid carbon steel of 0.85% carbon hardens most readily. They further observed that the manganese in a plain carbon steel had a marked influence on its hardenability. For instance, a steel of 0.40% manganese hardened much more readily than one with 0.25%, the carbon content being the same in both cases.

The above ideas were contained in the phrase "split transformation," which came into use, and this work of Portevin and Garvin was confirmed by French and Klopsch in their very thorough investigation of quenching media made at the United States Bureau of Standards, and reported to the American Society for Steel Treating in 1924. They also found that the Ar′ point did not suddenly disappear when quenching faster than a certain rate, leaving only the single transformation point, Ar″, but was gradually lowered by increasing the cooling rate until it reached the temperature of Ar″, thus producing a single change point on the curve.

Eight years later, in 1932, Bain, in his Howe Memorial Lecture before the American Institute of Mining and Metallurgical Engineers, gave the results of his investigations "On the Rate of Reaction in Solid Steel." Bain showed, as had Portevin and Garvin, that transformations at temperatures in the region of the higher Ar′ point, took place completely and with great rapidity, whereas those occurring at the Ar″ point were comparatively sluggish in reaching completion.



Portevin and Garvin's Cooling Curves for Cylinders of 1.07% Carbon Steel, Quenched in Water From 750° C. (1400° F.). Location of Ar″ was inferred from gradual change in direction of lower part of curve; the more gradual curve for the 14-mm. specimen is shown dotted below the curve for the 13-mm. specimen. Diameter of specimen and time from 700° C. to 200° C. are noted

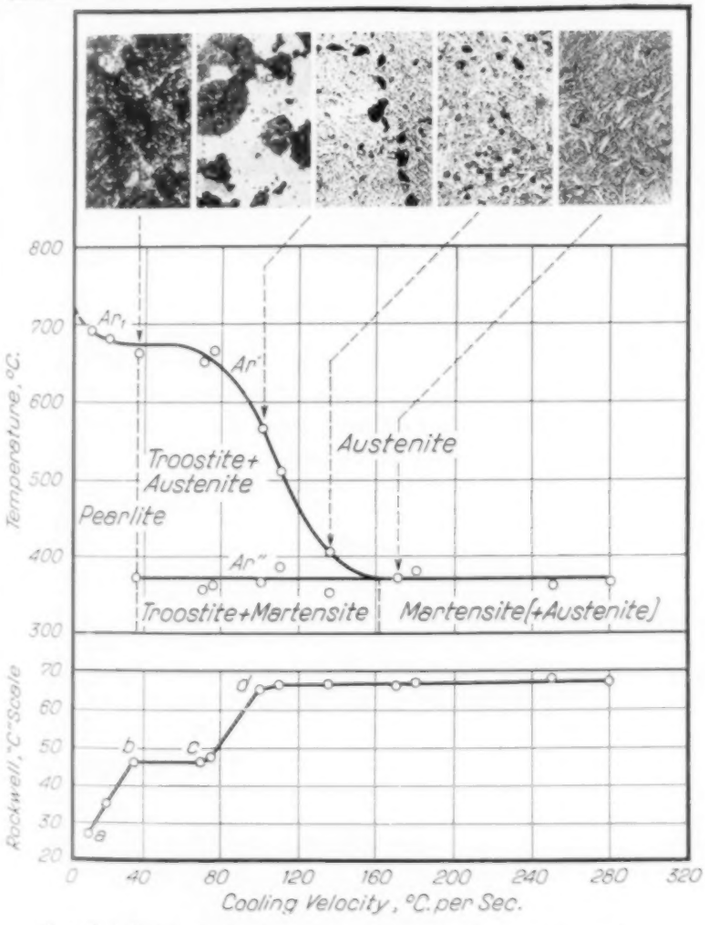
(This is not incompatible with the movie films taken by Wiester and reproduced in METAL PROGRESS in February, 1933, wherein he shows that austenite transforms direct to martensite by "fits and starts." Fairly large areas will transform completely in less than 0.05 sec., but these areas do not grow; other regions transform only after a considerable time. The *complete* transformation of the entire cross section at, say 600° F., will take days.)

In this research Bain quenched his samples into baths at certain temperatures and maintained the specimens at these temperatures for varying lengths of time and then cooled them very rapidly to room temperature and made microscopic examinations. He thus was able to determine the rate of transformation, and the time required for the entire metal to transform completely at all temperatures throughout the cooling range. It was found that the microstructure which resulted was characteristic of

the temperature *at which it formed* — in other words, that a steel which was quenched in a bath at a temperature between Ar′ and Ar″ and was found to be completely troostite, had not first transformed to martensite in cooling and then been further changed to troostite, but that the complex structure called troostite formed in this case directly from austenite.

Bain carried his work further in investigating the hardening of steel and the latter work was presented in his 1932 Campbell Memorial Lecture before the American Society for Steel Treating on "Factors Affecting the Hardenability of Steel." This work dealt largely with depth of hardening as it is influenced by various factors including composition and grain size. This work was very helpful, for most of us are aware of the fact that certain steels of roughly (I do not say "exactly") the same composition behave quite differently in hardening, and have become acquainted with the terms "normal" and "abnormal" as they apply to steels.

"Normal" steels appear to be steels having a relatively large grain size and which, when they have cementite as the excess constituent (as in a carburized case) show the cementite network to blend directly into the cementite plates of the pearlite. "Abnormal" steels, on the other hand, are usually characterized by a small grain size, and when they have a cementite network it does not blend into the cementite of the pearlite, but the cementite plates in the network are bordered by ferrite. "Normal" steels are, as a rule, deep hardening steels and "abnormal" steels are shallow hardening. Aside from the influence of "normality" Bain has found that fine grained steels have a higher transformation point (Ar) than coarse grained steels (rate of cooling and other factors being equal) and by virtue of this they must be cooled more rapidly for complete hardening — in other words, fine grained steels have a lower degree of hardenability, or are shallow hardening.



Relation Between Cooling Rates, Temperatures of Transformations, Microstructures and Hardnesses for a 0.96% Carbon Steel Quenched at Various Rates from 875° C. (1600° F.). Reprinted from H. J. French's book "Quenching of Steels" (Micros from prints kindly made by Bureau of Standards)

The normality or abnormality of steels is usually determined on specimens that have been carburized in a standardized way and so as to produce a hypereutectoid case. Grossmann has shown and Bain was able to confirm that it was possible to change the structure of a steel, known to be abnormal after ordinary carburizing, to a normal structure if it were carburized in a carburizer that prevented the access of oxygen to the steel. They both conclude that oxygen is conducive to abnormality and Bain classifies it among elements that cause shallow hardening, along with tungsten, cobalt, molybdenum, and vanadium. Manganese, chromium, nickel, silicon, and aluminum he classifies in the order given as promoting deep hardening.

Effect of Insoluble Carbides

To the majority of heat treaters the statement that tungsten, molybdenum and vanadium cause shallow hardening must come as a distinct surprise, to say

the very least. It seems more than likely that, within limits, all elements added to steel increase depth of hardening. The *appearance* of shallow hardening may be due entirely to the fact that a fixed testing procedure (with respect to the quenching temperature and time) is maintained without proper regard to the effect of the added element on the temperature of solution — that is, the transformation range — or on the time required for the solution of the carbides in the austenite.

Portevin and Garvin arrived at the conclusion that carbon decreased the critical rate of cooling of steel until it reached a minimum with the eutectoid (0.85 to 0.90% carbon) and then with further increase in carbon the critical rate was increased. This conclusion was valid because they used a quenching temperature of 1400° F. (760° C.). Now all the carbide of iron existing in a eutectoid steel is in solution at 1400° F.; however, in a steel of say 1.45% carbon all of the carbide is not in solution until a very much higher temperature is reached. Consequently when a 1.45% carbon steel is quenched from 1400° F. the austenite existing at that temperature contains a multitude of nuclei in the form of carbide particles from which transformation readily starts during cooling.

In the case of steels containing tungsten, molybdenum or vanadium, the carbide is not a plain carbide of iron but a more complex carbide containing some atoms of the added element, and these carbides are much less soluble in austenite than plain iron carbide. If either the temperature is not high enough or the time not long enough they remain partly undissolved, and act during cooling as nuclei for promoting transformation.

The use of aluminum for a deoxidizer when refining a heat of steel suggests this same idea of nucleation. In this case the finely dispersed particles of alumina in the steel may act as nuclei for the formation of numerous small crystals of austenite during heating, in the same manner that undissolved carbides act as nuclei for the start of recrystallization during cooling. Hence an aluminum-killed steel tends to be fine grained and shallow hardening.

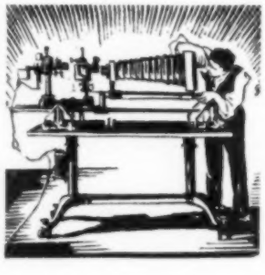
Houdremont shows (in some recent work reported in a paper read last year before the American Institute of Mining and Metallurgical Engineers) how the solubility of vanadium and tungsten carbides in austenite affects the depth of hardening. In a steel containing 1% carbon and 1% vanadium, when quenched from temperatures up to about 1782° F., the hardening was shallower than in a plain carbon steel of 1% carbon, but when a higher quenching temperature was used, the vanadium steel hardened more deeply than the carbon steel. This was not due to the production of a coarser grain in the vanadium steel quenched from the high temperatures — as a matter of fact, the hardened vanadium steel was extremely fine grained — but to the slower rate of solution of the carbide. Houdremont reaches the following conclusion:

"In steels containing such special carbides (vanadium and tungsten carbides) an increase in hardening power and a material change in the critical rate of cooling in comparison with plain carbon steels is afforded, entirely because of the solution of the special carbides."

Quenching from a temperature slightly above the transformation will harden a shallow zone in these alloy steels, not only because the relatively insoluble carbides are present as nuclei to start the transformations promptly when cooling in the quench, but also because there is a reduced amount of carbon in the austenite at the time of quenching. This decrease in the amount of carbon normally in solution is, of course, due to the presence of a large amount of it in the form of undissolved carbide.

* * *

Many more interesting considerations bearing on this subject might be brought into this article. Perhaps enough has been said to outline the development of two stimulating concepts. First was the idea of the split transformation, that austenite transforms directly into fine pearlite or troostite at temperatures below Ar_1 and above Ar'', and that austenite transforms directly into martensite at low temperatures. Second is the idea that *time* is a factor in these reactions or transformations in solid steel, and is influenced not only by temperature and alloy composition, but by austenitic grain size and existence of crystalline nuclei. The metallurgist who would safely heat treat steel to its ultimate properties must bear all these matters in mind.



Powder Metallurgy

notes on the new art

Some metals like molybdenum and tungsten are so refractory that they can only be prepared from sintered powders. This process has been applied to mixtures of metallics and non-metallics (bearings and hard carbides) and to magnetic alloys and mixtures of metals which can hardly be melted and cast. Alloys of highest purity and with interesting properties are new possibilities of the art

POWDER METALLURGY IS THE ART OF PRODUCING from powders by hot or cold compression a formed product, which upon subsequent heat treatment shows characteristics not generally obtainable by orthodox processes. It allows us to bring together elements of various densities such as graphite and copper and various melting points such as silver and molybdenum. It allows us to combine metals and non-metals such as carbon and tungsten. It allows any desired density of the finished product to specified dimensions within very narrow limits, eliminating machining. It reduces to a minimum the adsorption of gases during the manufacturing process, eliminating blow-holes and fissures, hot shorts, and like defects. In fact, it is an art analogous to plastics.

However, let nobody get the idea that we have here a panacea, an open sesame which will revolutionize the whole structure of metallurgy. Powder metallurgy has still a great many limitations and it will be many years before these limitations can be overcome.

To intrude a personal note, my acquaintance with powdered metals dates back to early in this century, when as an ore dresser I was concentrating and preparing tungsten and molybdenum ores for the electric lamp trade. Both these metals have such a high melting point that the refining by melting is uneconomical. No high frequency furnaces existed in those days; 5000° F. for molybdenum and 6500° F. for tungsten are even today uneconomical for mass production! The concentrated ores were therefore reduced by chemical processes to oxides and then reduced to metal with carbon or hydrogen. This metal was in very finely divided form — powder — and the utilization of these powders, not as additions but as individual metals, gave the start to the art of powder metallurgy.

Difficulties of the early workers in this field were myriad. Early efforts resulted in binding the finely divided metals with molasses, compressing the mass and relying upon the heat of sintering to eliminate the binding agent. Any number of binding agents were tried; sintering in various atmospheres followed and fair results were obtained. Then began a close study of grain size and grain structure; a study of methods of compression, and different types of furnaces. Comparatively recently, important companies have transferred operations to air condi-

By Charles Hardy
President
Hardy Metallurgical Co.
New York

Presented to the Chicago Section, American Institute of Mining and Metallurgical Engineers

tioned rooms; the finely divided metals attract moisture so readily that damp weather actually prevented operations. Cleanliness is also essential.

Tungsten and molybdenum are no longer in their "teens"; chemists and metallurgists have studied them and a literature is available. Powder metallurgy, however, as it applies to other metals is still very much in its infancy.

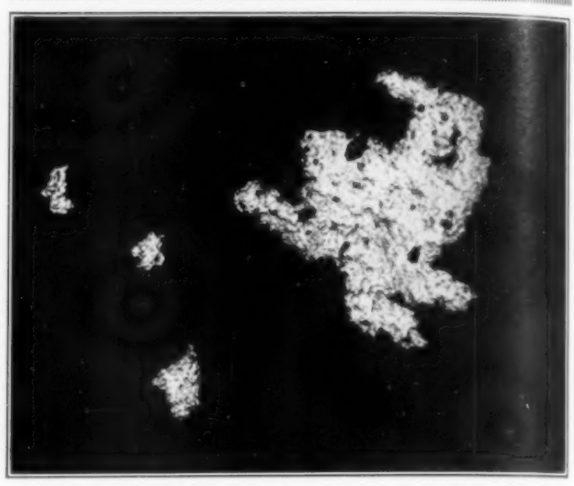
Producing the Powder

As the ultimate usefulness of this new art depends upon powder, let us start with describing the ways of producing powders. There are mechanical processes like crushing, grinding, stamping solid metal; chemical processes like precipitation from solutions or reduction of compounds; there is also the electrolytic deposition of finely divided metals.

In crushing, grinding and shot making, the grain structure is not very suitable. Powders produced by stamping are very flaky and if compressed alone cause laminations and thus weaken the finished product. Hence the principal metal powders are produced by electrolysis or reduced from their oxides by gases. In oxide reduction great care must be taken to ensure purity of the oxide itself; inclusions such as iron oxide, silica, or alumina, cannot be eliminated in subsequent processes; they stay and not only prevent a homogeneous mixture, but endanger the finished product.

Next in importance is the control of particle structure, particle size and mixture, or distribution of sizes. If all particles were alike, say pea-size, there would be too many interstices, the volume of a given weight would be far too great, and the entrapped air would be difficult to get rid of. It is therefore essential to determine the grain assortment, and this varies with the ultimate use for the powders. Buyers' instructions call for definite mesh assortments as, for instance, "Nothing coarser than 150 mesh, gradually reaching 325 mesh, but in any case 30% finer than 325 mesh," or, "All passing 325 mesh." A powder of the latter specification contains, of course, a great many particles of very minute size and the entire mixture has the necessary variation in grain size.

Next in importance to grain assortment is the weight of a given volume of powder. This is called apparent density. A definite density is aimed at for each application; starting from the apparent density of the powders, one has to calculate whether the compression ratio must be



Particles of Chromium Powder and One Relatively Large Flake, Magnified 500 Diameters

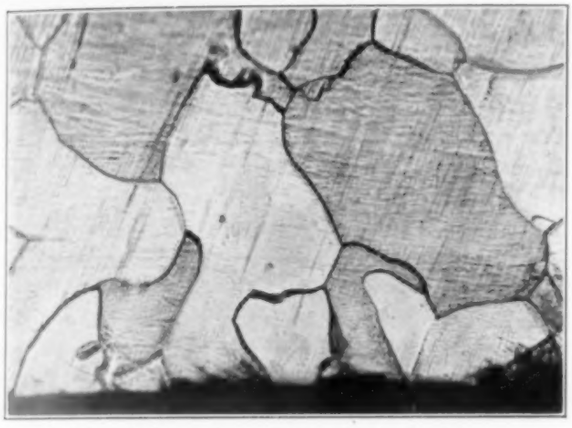
2 to 1, 3 to 1, or any other ratio in order to ensure the desired density of the finished article, otherwise no continuous operation can be contemplated. The manufacturer of the powders must not only be able to determine and to control the particle structure and size as well as the apparent density of the powder, but he has also the problem of varying these characteristics according to the requirements of his customer and to do this economically. Screening alone will not do it; he would be left with too large an over-size and under-size thus making his operation quite uneconomical.

In the production of tungsten and molybdenum powders, the method of precipitation has been so carefully studied that through control of the time element and of heat at the time of precipitation, grain sizes in the exact proportion now demanded can be produced. In the electrolytic deposition of metal powders, control of current density, temperature of electrolyte, proportionate size of anode to size of cathode and the use of an addition agent have allowed the production of a variety of differently shaped powders and powders of varying density. (For instance, it is possible to produce copper powders with apparent densities ranging from –1 to 4.) This difference in density is of the greatest importance when very light material such as powdered graphite has to be mixed with the metal.

The next step is the mixing of the powders ready for the dies, where more than one powder

is called for in the finished product. Powder metallurgy is particularly applicable for parts made from several elements. Nobody would think of compressing powders to make an ingot of tin or an ingot of copper, except for investigational purposes, although this is the economical way to prepare a mass of tungsten.

In almost all cases we have powders with very different densities and unless the mixtures are very homogeneous a uniform finished article



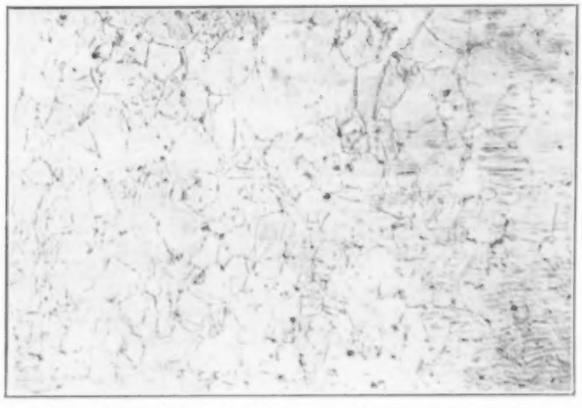
Edge of Pure Iron Strip, Made by Pressing Iron Powder, Heat Treating, Rolling and Annealing. Magnified 200 diameters

cannot be expected. For that reason the powders are generally mixed in tumbling mills or continuously sieved for a long time — from one to 24 hr. — so that each particle of one metal or non-metal can get close to each particle of the other. Often the mixing operation takes place in a mill or tumbler in a hydrogen atmosphere. The art has been so well perfected that discs, after compression were cut into five parts and each part separately analyzed by the Bureau of Standards; the greatest difference did not exceed the analytical error of the method used.

Technique of Compression

We are now ready to measure a required quantity, fill the dies and compress it. I stated previously that powder metallurgy allows the pre-determination of the density of the finished article — as an oil-less bearing. Density can be regulated by the selection of the density of the powder and the amount of pressure per square inch area of the pressed article. Low density articles contain a large number of small pores more or less equally distributed throughout the pressed article. Sometimes the porosity is artificially increased by mixing with the powders some volatile salt which volatilizes during heat treatment.

Variation of pressure to ensure different density implies, at the same time, variation of the compression ratio. This is best explained by an actual example. In order to make a copper article with the density of cast copper (8.3) it would be necessary to compress a copper powder with an apparent density of 2.75 at a ratio of 3 to 1. If a copper powder of the density 1 is used, it would have to be compressed 8.3 to 1. (In one case we have actually had compression ratios of 16 to 1.) This compression ratio demands dies with a well depth of three or eight



Structure of Synthetic Brass. Pure copper and zinc powders, 65 to 35 by weight, were pressed into a rod, heat treated and re-pressed. Magnified 200 diameters; chromic acid etch

(or sixteen) times the depth of the finished product, based upon the above examples. Denser powders are used for the higher compressions.

This well depth offers one of the difficulties in powder metallurgy as it limits us with respect to the heights of the pieces which we can press. Generally, no attempt is made to press parts deeper than 8 in., or at best 10 in. At a compression ratio of 3 to 1, a piece of 8-in. depth requires a 24-in. die and at least the same height, as space has to be allowed for the plunger. It will be readily realized that a clearance of the press in excess of 60 in. is not feasible. Besides,

the plunger has to travel 60 in. representing a great deal of lost energy.

Furthermore, the fine powders under compression offer resistance — a resistance which increases with the depth, and unless special precautions are taken with such large pieces, the density at the top and at the bottom may be several points apart.

The dies must resist the wear and friction of the powders. This wear varies according to the metal compressed; for instance, chromium powder will wear a die more rapidly than will tin powder. The die steels are frequently protected by hard chromium plating. In special cases dies are made from hard alloys or carbide, or lined with such compositions as "hastelloy," "firthite" or "carboloy."

Next, it must be considered that the difference in density between the metal piled up in the die and the compressed part consists mainly of air. Provision must be made for this air to escape during the compression, otherwise air cushions are built up inside the finished piece. Upon subsequent heat treatment the air in such a pocket expands, forms laminations in the pieces and even causes the pieces to break apart. This difficulty can be avoided by proper clearance between plunger and die. This clearance must be carefully limited, otherwise the air forced out of the die would carry the finely divided powder with it. Another way to overcome the difficulty is to taper the die slightly.

Presses Available

Speed is also a factor. A slow stroke is liable to entrap more air, than a quick, rapid stroke. Therefore, according to the shape and the depth of the article to be made, the producer has the choice between the slow method, such as a hydraulic press, or more rapid methods in gear presses, friction presses, knuckle presses, or even drop hammers.

Charles Hardy and powdered materials are old adversaries; early in the century he was concentrating tungsten ore by magnetic methods. He has written much about tungsten, molybdenum, the alkaline earths and other minor metals. His schooling was had in Germany, England and America (Columbia University). Photo by Keystone, N. Y.

Presses are built for operation with single dies or multiple dies. The pressure required varies from as little as 2 tons per sq. in. to 75 or 100 tons per sq. in., according to the metals to be compressed, the density required, and the size and shape of the pressed piece. The speed with which the press operates varies with the type and size of the press. The highest speed known to me is in the manufacture of contact points where the press operates at the rate of 120 pieces per min. Of course automatic feeding devices are then necessary for rapid feeding of a definite volume of powders to the die.

Heat Treatment of Blanks

After compression, we have only the agglomerate of the elements that make up the finished piece. While the pressure is sufficient to hold the component parts together allowing the pieces to slide on a belt, they are not strong enough for service. Naturally no alloys have been formed; these are formed by heat treatment — ordinarily a sintering process which varies with the type of material to be treated and the ultimate characteristics expected of the finished piece.

As powder metallurgy was first applied to tungsten and molybdenum, I will first describe the method employed with them. The compressed bar is held between two electric terminals in a tight container filled with hydrogen. Current is then turned on; heat developed by resistance sinters the bar into a coherent mass. Such resistance sintering has been tried for various combinations of metals and has been quite successful. It is, however, necessary to control the process carefully so that the finished piece does not get too hot, and yet hot enough. Sintering is mostly adopted for parts that require the best physical and chemical characteristics. Other methods of heat treating vary from sintering by electric resistance in any other re-

during gas, to sintering by radiated heat, the parts being in closed boxes into which a small amount of charcoal is thrown which will combine with the oxygen of the air and form a reducing atmosphere of carbon monoxide.

Temperatures vary, depending upon the composition and intended ultimate purpose of the finished part. In working out a new combination we begin the heat treatment experiments at two-thirds the melting temperature and raise or lower it according to the very simple method of "trial and error." Unfortunately no definite rules can be set down as yet. Practice varies with each plant using metal powders, as hardly two plants work on the same composition, and even if the same composition obtains, the finished pieces are usually wanted for varying purposes. In the case of alloys of the iron group, the sintering temperature quite often rises very close to the melting range of the alloy. During this high temperature process certain distortions, shrinkages or swellings take place which must be taken care of. In most cases the sintered pieces are placed in a coining press and restruck in proper dies, and the manufacturer will usually guarantee dimensions to within 0.001 in.

For so-called oil-less bearings, the powders are compressed with the intent of leaving pores for oil absorption. The amount of oil can vary considerably, depending on the technique — there are parts which absorb 5% their volume of oil and others which absorb as much as 25%.

Where ingots rather than shapes are compressed from a number of various powders (or of particularly pure iron powder) they are made with the intention of subsequent rolling or drawing. Subsequent restriking to exact dimensions is unnecessary. Such ingots can be forged, swaged, rolled, or drawn, and the resultant material has, in most cases, a better combination of strength, toughness and ductility than the material produced by orthodox methods. Absence of oxides, carbides, and gases in general, the predetermined grain structure and fine distribution of the component elements, undoubtedly account for the better tensile properties and for the more uniform physical and chemical characteristics. To cite one example, it is possible, by this method, to make a stainless "steel" with exactly 18% chromium, 8% nickel, and practically no carbon. Since carbon is the cause of many anomalies in the behaviour of this new alloy, the process of making a carbon-free alloy is very attractive. As no slagging losses need be accounted for, this method of compression offers great possibilities for alloys of exact analysis. In addition, hard alloys can be produced and compressed to exact size in compositions which, if cast, would be too hard for subsequent machining except at great expense.

Widespread Use of Product

The field of application is already very wide. Such examples as are cited below are only an indication of what is now being done on a sufficiently large scale to consider the use of metal powders as a definite established practice.

Tungsten and molybdenum, when used as pure metals, are entirely based upon powder metallurgy. You are all familiar with many of the applications in the form of lamp wire, radio cathodes, contact points. A number of publications are available concerning the production of tungsten wire, a recent one being by W. P. Sykes in Metal Progress, March, 1934. The automobile industry is using millions of bearings, bushings, and inserts made of compressed powders, and the railroads have commenced to use similar bearings, wedges, and wearing plates. The electrical industry makes innumerable parts from powders: dynamo brushes, generator brushes, contact points, commutator segments, rotors, spark plugs — to mention a few items. The dental industry uses powders for bridges, investment metal and many unusual compounds. In the arts, coins and medals have been successfully struck. One of the latest developments is the manufacture of the new magnet alloy of especially high power by the General Electric Co. It is composed of nickel, aluminum, cobalt and iron, and, according to their publication, the best results are obtained by the compression of the powders into the final form; the resultant alloy if cast is so hard that machining appears impractical.

Welding rods have been produced by mixing the component elements and adding the necessary flux to these powders. It is reported that for arc welding, the uniform distribution of the metal and the flux has a great advantage over the cored or coated rod. Powders are also sprayed on the regular bare welding rod or mixed with a coating material and thus adapt the filler metal to the alloy composition to be welded.

Enough has probably been said to indicate to the reader how the new art of powder metallurgy can be applied to his particular problem — an important consideration, for applications are rapidly increasing. Even today, we are only at the doorstep of an apparently new metallurgy.

Some Good Books

to read and own

So much has been written and printed in books that a fair portion of a man's education consists in knowing how to build up and use a good library. Here are some notes on a number of books that are well worth a man's money and his study

Steel Wire

STEEL WIRE, ITS MANUFACTURE AND PROPERTIES. By Maurice Bonzel; translated by Kenneth B. Lewis. 495 pages, 6¼x9¾, 414 illustrations. Engineers Book Shop, 168 East 46th St., New York. Price $15.00.

ASIDE FROM A somewhat less comprehensive book by A. T. Adam, this is the only one known to the reviewer that discusses the manufacture of wire from the viewpoint of modern physical metallurgy. Hence the price is not excessive. When the purchaser has spent his $15 he has half the scientific library of the industry.

M. Bonzel, the author, is rarely placed. An engineer by education who got his metallurgy under Leon Guillet, he is general manager of the wire mills of Établissements Bohin. He is fortunate in having an inquiring mind; he respects the traditional lore of the industry but studies each of its practices, and by combined laboratory and plant tests decides what is essential, what is non-essential and harmless, and what is positively detrimental to a good product. Probably he is not unique in this attitude of mind; there are doubtless many other inquiring souls in his industry. He *is* almost unique, however, in having a disposition plus the permission to share this information with his competitors and the public.

The translator is quite as well fitted to his task as the author. He needs no introduction to technologists in our own wire industry. To others it may be said that 25 years of work with wire mill machinery has taken him to nearly every mill on this continent, where he has become thoroughly familiar with American practice, both traditional and advanced.

While M. Bonzel's text is confined to French practice — principally wet drawing — little that he has to say is without direct application to conditions in this country. A typical example of his critique of existing practice goes about as follows: The practical operation of patenting is described and the microstructure of high carbon rod is illustrated, both as properly treated and after various improper treatments. Next the published literature of importance is summarized and criticized in the light of his own experience. Certain factors not discussed by others are then examined, such as time at high temperature, diameter of wire, and composition of the steel. Lastly he gives the metallurgical theory, and cites the fact that the most recent researches of Davenport and Bain were required to give a logical foundation for the traditional practice, and to prove that quenching from above Ar_1 (say from 1700° F.) into a lead bath held pretty closely at 900° F. is the exact way to give the finest pearlite possible, without any masses of soft ferrite on

the one hand or hard, acicular constituent on the other. Finally, based on these experimental and theoretical considerations, he concludes that there is no necessity for a long soak above Ar_1 and furthermore that a long stay in the lead is detrimental. For that reason the patenting furnaces at his mills are short, and the strand speeds (generally high) and the position of the sinkers in the lead pot are adjusted to the diameter of the rod.

It is to be hoped that the appearance of this work marks the end of an epoch wherein the heat treaters and wire men have been sneering at each other. The metallurgists were taunting the wire men for various illogical rule-of-thumb practices, and the wire men were snickering at the metallurgists for advocating changes that were apparently sound in theory but for occult reasons won't work on wire. Bonzel the author and Lewis his translator are both men who are broad-minded enough to see both sides of such situations. More power to their clan.

Oxide Coatings on Metals

REVIEW OF OXIDATION AND SCALING OF HEATED SOLID METALS. A publication of the Department of Scientific and Industrial Research. 104 pages, 6x9½ in. His Majesty's Stationery Office, London, W.C.2, England. Price 2s 6d.

SINCE THE WAR the British government has fostered fundamental researches in various industries by granting funds for a portion of the expense involved in approved projects. One subject thought worthy of special consideration is the scaling of hot metal. This has enormous practical importance, not only causing perhaps 3% wastage during heating for forging, rolling or other hot work, but also the type of scale influences such subsequent operations as pickling, bright annealing or painting. Likewise more information is needed for a further development of high alloys for heat resistance.

Preliminary to actual work it is, of course, desirable to survey what has already been found out, and this little volume contains six monographs or critical reviews of the literature on several phases of the question. The plan of action adopted in this case is to be recommended for its speed and thoroughness. The names of the authors of the sections (headed by Ulick R. Evans, L. B. Pfeil and J. C. Hudson) are a sufficient guarantee of quality.

After reading the book, one has the feeling that one could shut his eyes, thrust in his hand, and come out with a question worthy of extensive investigation. There seems to be but one principal finding that has been checked and back checked; it has grown out of the comprehensive work by Jominy, Murphy and Upthegrove at the University of Michigan. Correlating the work of about ten other investigators, Dr. Hudson finds that the rate of oxidation of iron or mild steel in air or oxygen can be computed from the formula

$$K = CT^{9.82}x10^{-30}$$

where K is the thickness of metal oxidized in thousandths of an inch per hour; C is a constant, 1.664 for air, 2.316 for oxygen; and T is the absolute temperature. Even this formula holds only up to 1000° or 1100° C. (2000° F.), and beyond that temperature the experimental data are quite scattering. Nothing much can be said about the influence of minor constituents of the furnace gases, nor of the composition of the steel.

Any research on scaling cannot be planned with much reliance on a theoretical background, for such does not exist. For instance, there are six different iron-oxygen equilibrium diagrams (some quite fragmentary), but all by first-class investigators, and all widely varying in their interpretation of the region between 70 and 78% iron (Fe_2O_3 and FeO respectively). Some ten different phases have been proposed between these limits, although four is a more probable number. It is even questioned by several investigators whether FeO really exists as a true compound at *any* temperature!

Under these circumstances it is not surprising that what is known about the subject of scaling has been acquired principally by isolated observations. As summarized by S. A. Main, in the resumé of his section in this book, "Fuel fired furnaces have been steadily improved in design, mainly under the urge for economy and efficiency of working, but concurrently attention has also been given to avoidance of oxidizing conditions, as well as of high local heating of the charge due to direct impingement of flame. Old standing false ideas as to the reducing character of a rich flame have been disproved, and the oxidizing action of the products of combustion, carbon dioxide, sulphur dioxide and steam, even in the presence of considerable proportions of combustible gas, is established. Water vapor, next to oxygen itself, is shown to be the most active oxidizing agent. Sulphur is specially obnoxious and is even more active in a reducing atmosphere where it exists as H_2S or an organic compound,

than in an oxidizing atmosphere as SO_2 or occasionally the higher oxide. The use of instruments recording composition of the gases has, so far as they have been applied, had a specially beneficial influence."

Textbook on Steel

AN INTRODUCTION TO THE METALLURGY OF IRON AND STEEL, by Herbert M. Boylston. Second Edition, 563 pages, 6x9 in., 420 illustrations. John Wiley & Sons, New York. Price $5.00.

WHEN WRITING A BOOK about the entire production of iron and steel from its ores, its rolling, forging or casting into shape, and the properties of the heat treated alloys, an author must be embarrassed with a multitude of riches. It is a matter of deciding what must be left out rather than what can be put in. Reasonable bounds would be burst if it were anything but an "introduction." Naturally much of interest to the specialist must be omitted in the interest of the student or general reader, and the specialist is apt to get a wrong view of the real usefulness of such a volume.

Professor Boylston has wisely told much of his story in pictures, and of these he has a notably fine collection, unusually well reproduced and printed. In comparing a copy of the first edition, it was found that several of the cuts had been copied by the reviewer — evidently as the best views available of the particular subject.

Experience with the book as a teaching text has undoubtedly convinced the author of its sufficiently broad coverage, as only minor additions or changes have been made in the first edition other than the extension of the tonnage statistics and accounts of the Brackelsberg melting furnace, the Aston process for wrought iron, and the molybdenum-tungsten high speed steel. It may be regretted that paragraphs on alloy cast irons, methods of controlling grain size and its practical utility, and the new families of stainless steels and high strength structural steels were not also included. On the other hand, ingot practice is treated in a unique manner (as would be expected by those familiar with Boylston's early work), although one finds only a footnote referring to the very important cooperative researches now going on in England on the heterogeneity of steel ingots. One notes with pleasure a full discussion of annealing practice and its effect on metal of various history — a matter too often dismissed with little more than a definition.

All About Welding

SYMPOSIUM ON THE WELDING OF IRON AND STEEL. Two volumes, 676 and 974 pages respectively, 5¼x8 in. The Iron and Steel Institute, 28 Victoria St., London, S.W.1, England. Price £ 2 4s 0d postpaid.

THIS ASSEMBLAGE of 150 papers by as many experts from all over the civilized world, is the result of a comprehensive discussion organized by the Iron and Steel Institute wherein 15 other engineering societies in Great Britain participated. Numerous references to this great body of information have been made in METAL PROGRESS since the preliminary pamphlets appeared; the reader may refer to an editorial last June entitled "Heavy Welding Abroad" for an idea of the contents of Volume I. Volume II contains an equally fine group of papers on welding technique, metallurgy, and inspection.

A better title for this work would be "International Handbook of Modern Welding Practice." It certainly should be in the working library of every engineer or production man who is in charge of welding operations, or who is interested in this new art of joining metals — and that really means every wide-awake metallurgist, does it not?

The Metals Other Than Iron

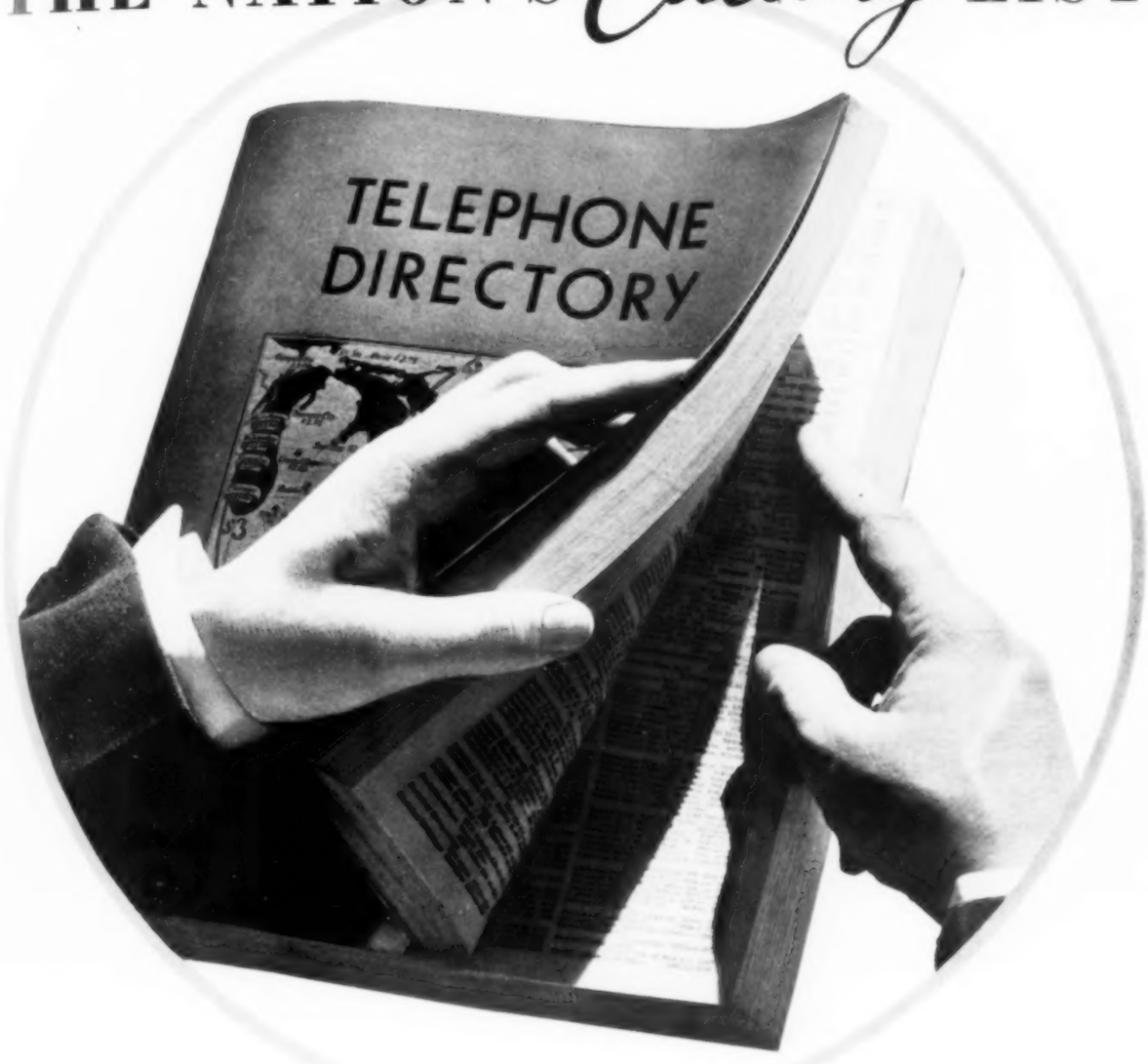
MODERN USES OF NON-FERROUS METALS. A collection of 22 essays by prominent metallurgists, edited by C. H. Mathewson. 426 pages, 5¼x8 in. Published for the Seeley W. Mudd Fund by the American Institute of Mining and Metallurgical Engineers, New York. Price $3.00.

WHILE THIS BOOK is intended primarily as a guide for young men thinking of metallurgy as a vocation, the book contains a useful summary of facts good for many an elder who has specialized in this, that or the other branch. Some of the chapters follow talks that have been given at annual dinners of the Institute of Metals, and the attendance at the latter warrants the belief that even a lead metallurgist, for instance, would with interest learn what Jesse Betterton thinks are the most interesting and important facts about lead refining and use. Excellent typography, press work and binding are in keeping with the eminence of the authors. Indeed, a very satisfactory, comfortable little book.

As all editors and publishers know, the great-

(Book reviews are continued over leaf)

THE NATION'S *Calling* LIST



THE telephone directory is the nation's calling list. Millions of people refer to it daily—in homes and offices and in public pay stations. It is the busiest book—it plays a part in countless activities.

For the names in the telephone book are more than names. They are friendships and homes and families. They are bridge parties and golf games—business successes—buyers and sellers of wheat or pins or skyscrapers.

More than 12,000,000 names are listed in the directories of the operating companies of the Bell System. You can go straight to any one of these millions of people—easily, quickly and economically—by telephone.

The classified directory is an important feature of your telephone book. It is a handy, reliable buying guide —a quick, easy way to find "Where To Buy It."

BELL TELEPHONE SYSTEM

Good Books to Own

est trouble is not to get a thing written and printed, but to get it read. Here is a book intended for high school boys; it is well written and well printed. Now looms the real question: How can it be placed in the hands of boys who ought to have it; how can they even be told there is such a book available?

It is to be hoped that the Seeley W. Mudd fund, which guaranteed the deficit (if any), has enough surplus to finance some effort toward solving this real problem. Why not distribute a thousand copies to chemistry teachers in the large high schools in this country, the authors and potential authors of the textbooks used by the youths? If some metallurgical information could be got into these books it would help, eventually. In one of them now before the reviewer, zinc is awarded two pages; galvanizing and alloying are mentioned but the only use for the metal honored with a description is that of zinc dust for a reducing agent in chemical reactions. Seven compounds are described as salts of the principal acids, but no hint as to anything the compounds might be good for. In other words, metals are taught as basic elements and ingredients of salts and compounds, rather than commercial substances with characters of their own.

Is it any wonder that the high schooler with such a text in hand has not the faintest appreciation of the importance of the zinc industry — or even knows that there is such an industry offering opportunities for a life work and success?

Elementary Text

THE WORKING, HEAT TREATING AND WELDING OF STEEL, by H. L. Campbell. 185 pages, 5¾x9 in., 91 illustrations. John Wiley and Sons, Inc., New York. Price $2.25.

THIS BOOK is a brief but very interesting discussion of the working, heat treating and welding of steel. The descriptions of methods and machines are clear and the illustrations are especially good. It covers the manufacture of wrought iron, the steel making processes, the chemical composition of steel, classification of steel by composition and uses; physical testing of steel; the effect of temperature changes on the mechanical working of steel; processes and equipment for working steel. Mr. Campbell's text on the physical constitution of steel is illustrated with some excellent photomicrographs. Processes and equipment used in heat treating steel, the nature of alloy steels and their heat treatments, processes and equipment for welding steel, and the preservation of steel complete the principal items discussed. The book is supplemented with a series of laboratory assignments and there is a page of references to books on the metallurgy of steel which cover the various processes in greater wealth of detail.

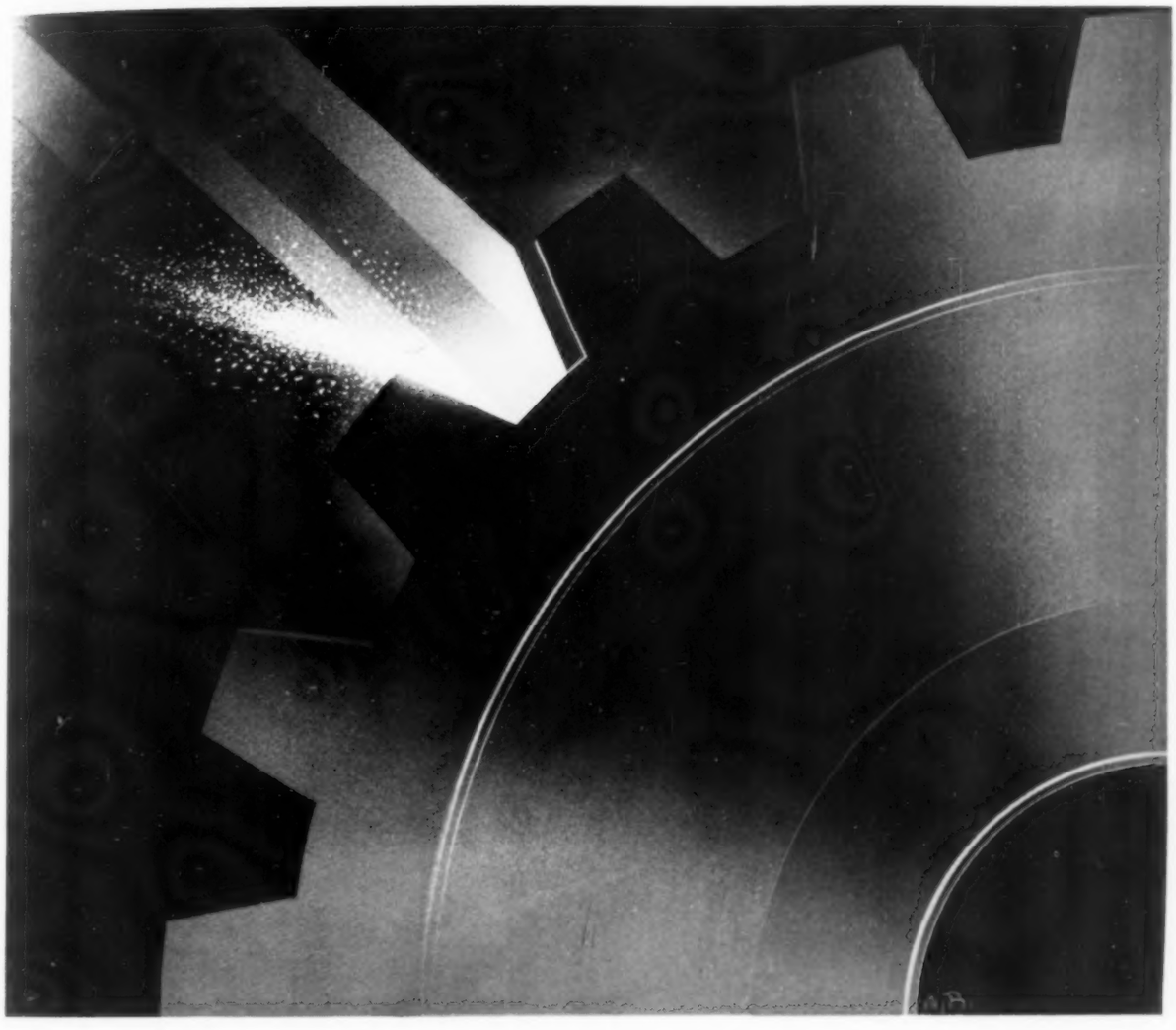
The book should be excellent for handling a sophomore class either in a metallurgical department or a mechanical engineering department and while it is too brief to replace the more detailed knowledge furnished by other larger and well known text books it should be of great use in putting over the story of steel to the younger students. HERBERT M. BOYLSTON

Physical Metallurgy

AN INTRODUCTION TO PHYSICAL METALLURGY, by Leland Russell Van Wert. 272 pages, 6x9 in., 200 diagrams and photomicrographs. McGraw-Hill Book Co., New York. Price $3.00.

AT A RECENT MEETING of the Electrochemical Society commemorating the 50th anniversary of the discovery of the present method of aluminum reduction, Arthur V. Davis, one of the pioneers, said that the history of the Aluminum Co. of America could be divided into four epochs: First, they had to find out how to make aluminum; second, they had to find somebody to buy it; next, they had to find out how to make some money on the transaction; last, they had to find out something about the metal and what else it could be used for.

This generalization applies equally to the other branches of the metal industry. Probably most readers of METAL PROGRESS are interested in the last of Mr. Davis's epochs and can use Dr. Van Wert's book to advantage. It tells something of the methods whereby the investigator studies the inner structure of metals and alloys, and the progress which has been made in systematizing an enormous mass of experimental data. The aim, of course, is to find out what new things the old metals and alloys are good for, how they can be changed by appropriate treatment either mechanical or thermal, and how new alloys can be devised to meet demands beyond the inherent capacity of the older ones. *(Continued over leaf)*



MOLY helps to cut finishing costs

TAKE gears, for example: If in their production the distortion can be so minimized—and uniformly predicted—as to eliminate the necessity of grinding before lapping, the cost of one operation is saved.

This is exactly what one manufacturer was able to do by adopting Nickel Moly steels (SAE 4600 series) for his gears.

Similarly, throughout other operations in the production of finishing steel parts—in forging, heat-treating, carburizing, machining—Moly steels have made it possible to cut costs substantially.

Our files may contain experiences or case histories paralleling some particular problem of your own. These data, as well as the co-operation of our experimental laboratory, are at your disposal. Meantime, our technical book, "Molybdenum," and our periodical news-sheet, "The Moly Matrix," will gladly be sent you on request.

CLIMAX MOLYBDENUM COMPANY, 500 FIFTH AVENUE, NEW YORK

CUTS COSTS CLIMAX Mo-lyb-den-um CREATES SALES

Good Books to Own

Dr. Van Wert, lecturer on metallurgy in Harvard University, joins a distinguished company of metallurgists who have treated this important new branch of an old art. Three countries have already produced books of outstanding merit. In 1914 came "An Introduction to the Study of Physical Metallurgy" by Walter Rosenhain. He gave much attention to the relation of mechanical tests to the microstructure, and so produced a most readable and understandable volume, probably of most "practical" value. Shortly thereafter came "A Text Book of Metallography" by Gustav Tammann (translated from the German in 1925 by Dean and Swenson) which looked upon metals and their alloys from the scientific viewpoint of physical chemistry — pretty stiff reading! Our own countrymen Zay Jeffries and R. S. Archer published their "Science of Metals" in 1924. If this notable book can be briefly characterized, it may be said that Jeffries and Archer looked upon a metal as a crystalline aggregate, and discoursed largely on methods of changing the size, orientation, composition, and constitution of these micro-grains, and then explained how such changes affect the mechanical properties of commercial metals.

The book now under review is smaller than any of these predecessors, which, of course, means that many important aspects of the subject are omitted or sketched briefly. On the other hand, the author has had the advantage of a great amount of new information gained with the X-ray. Thus is the search for fundamentals pushed even deeper and to more minute particles than can be seen with the most powerful microscope. Many interesting questions about space lattices, grain fragmentation and preferred orientation can be solved in this way; Dr. Van Wert's long chapter on the microconstituents of alloys is a masterful summary of our present knowledge about atomic arrangements. It is no disparagement of the book nor of the new science to say that in this respect the researcher is far in advance of the application of his findings to the art of working, fabrication, and heat treatment of the common metals.

This has always been the case. No one has yet got far beyond Dr. Rosenhain's beginning at the task of correlating even the visible microstructure and the physical properties.

International Congress

METALLURGICAL CONTRIBUTIONS, Congrès International des Mines, de la Métallurgie et de la Géologie Appliquée. 476 pages, 8½x11 in., 330 figures, paper bound. Revue de Métallurgie, Paris, France. Price, 86 francs 60.

JUST THE FACT THAT 45 countries were represented at the seventh session of the International Congress of Mining, Metallurgy, and Applied Geology, held in Paris last October, is ample guarantee of an interesting and permanently valuable assortment of papers. The contributions contained in the present volume are the ones solicited by the program committee, and are usually in the nature of reviews of important specific phases of modern metallurgy. A second volume is scheduled to appear this spring containing unsolicited contributions to the Congress, and the editors inform us that a supplementary pamphlet containing verbal discussion will also be printed.

This first volume is divided into seven sections, on fabrication of iron and steel products; fabrication of non-ferrous products and electrometallurgy; ferrous alloys; non-ferrous alloys; foundry practice; transformations in metals, treatment, and uses; and testing. The roster of authors contains such prominent names as Sauveur and Bain from the United States, Britain's Sir Robert Hadfield, France's Portevin and Guillet, Germany's Guertler, Sweden's Benedicks, and Italy's Giolitti. Space will only permit a brief summary of two of the papers in the present volume.

M. A. Pavloff of the U.S.S.R. comments in an interesting manner on modern blast furnace design. Dimensions, he states, have changed so completely in recent years that many engineers believe it is no longer possible to calculate on the basis of old relationships. He does not agree with this, and shows how he arrived at figures for what he would consider ideal dimensions of a 1000-ton furnace. These turn out to be very similar to the dimensions advocated in 1930 by the Blast Furnace and Coke Association of the Chicago District, with the essential difference that Pavloff's furnace is 3 ft. higher and slightly wider at the throat.

Pavloff attributes the opening of a new period of development to the construction in 1927 of Jones & Laughlin's furnace No. 5, which averaged over 1000 tons per day for a period of a year — an unprecedented record. In 1931 the United States